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# Velocity-Based Training as a Method of Auto-Regulation in Collegiate Athletes

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**Velocity-Based Training as a Method of Auto-Regulation in Collegiate Athletes**

By

Damien Levon Fisher

Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

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**MASTER'S THESIS**

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Damien Levon Fisher

May 11, 2016

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A Thesis
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**Abstract**

The purpose of this study was to determine the effect of Velocity-Based Training (VBT) as a form of auto-regulation on strength and power metrics in collegiate athletes. Seventeen NCAA Division II collegiate softball players participated in the study, and were randomly assigned to either a control group or a VBT group after being paired according to strength-bodyweight ratios. A six-week training period was completed, with the control group performing back squats and bench press with a conventional fixed-volume program, while the VBT group performed back squats and bench press with a variable volume program in which volume was determined by the number of sets competed before a 10% drop-off in movement velocity, as measured by an accelerometer device. All training outside of back squat and bench press was identical between groups. Subjects were tested for vertical jump height (VJ), mean rate of force development (MRFD), peak power (PP), peak force in an isometric quarter-squat (PF), and bench press one-repetition maximum (BP 1RM) before and after the training period. PP ($F$ [1, 13] = 4.892, $p$ = .045, $\eta^2$ = .273) significantly increased over time for both groups (3395.33 ± 553.6 W to 3545.83 ± 549.3 W for the control, 3559.35 ± 462.4 W to 3707.69 ± 337.8 W for VBT). No significant interactions were found between time and group, or between groups for any dependent variables. These results indicate that the use of VBT to regulate training volume in collegiate softball players may be as effective as conventionally periodized training.

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# Chapter I

## The Problem and its Scope

### Introduction

Strength and conditioning coaches are constantly looking for the most effective and efficient means of programming for the development of athletes. The foundation of successful exercise programming lies in the principle of progressive overload. Consistent overload is necessary to stimulate continued adaptation to training. Over time as the athlete improves their physical qualities, acute variables including, but not limited to, load, volume, time under tension, density of training, contraction regime (i.e. eccentric vs. concentric), range of motion, and/or frequency must be progressively increased to maintain an effective overload. The concept of periodization, or systemic variation in specificity, intensity, and volume, grew out of the need to progressively overload athletes without overtraining (Baechle & Earle, 2008).

While traditional periodization models are effective at increasing strength and power in athletes, limitations are present, especially in a collegiate setting when there are many times throughout the year that strength and conditioning coaches are unable to work with the athletes (Kraemer & Fleck, 2007). The primary limitations revolve around the inability of traditional methods to accurately predict the athlete's strength levels and capabilities on a day to day basis. As no attempt is made to determine the athlete's daily readiness levels, the coach has no reliable way of knowing if the prescribed load or training volume is correct for the athlete on the given day (Kraemer & Fleck, 2007; Jovanovic & Flanagan, 2014; Mann, 2013).

Auto-regulation methods are ways to modify acute training variables to match an athlete's readiness level before a given training session (Jovanovic & Flanagan, 2014). Readiness tests are typically conducted prior to or during training, with the session being tailored to an athlete's readiness to train according to a predetermined protocol. If properly implemented, auto-regulation can allow for optimization of training and the avoidance of undertraining and overtraining (Kraemer & Fleck, 2007). Many methods of auto-regulation exist with some of the most common being Flexible Periodization, Auto-regulatory Progressive Resistance Exercise, Rating of Perceived Exertion, Heart Rate Variability, and Velocity-Based Training. While traditional periodization and other auto-regulatory methods rely on percentages based off of a one-repetition maximum (1RM), which can change throughout the training program, VBT adjusts the training session based on the velocity at which the chosen exercise is completed (Jovanovic & Flanagan, 2014). The presence of instantaneous knowledge of performance in the form of velocity readouts allows for immediate adjustment according to the athletes readiness level. VBT can be implemented in a variety of ways, including estimating 1RM, adjusting the number of sets and/or repetitions both inter- and intra-set, and adjusting the load that is performed for a given number of sets and repetitions (Jidovtseff, et al., 2011; Mann, 2013).

There are several factors that may influence the effectiveness of VBT as a form of auto-regulation. Research indicates that when maximal intended velocity is applied during an exercise, significantly greater increases in strength and power are observed over training performed with equal loads but lower velocities (Behm & Sale, 1993; Jones, et al., 1999; Gonzalez-Badillo, et al., 2014; Pareja-Blanco, et al., 2014; Padulo, et al., 2012). It appears as though increasing intended velocity results in greater activation of large motor neurons and the Type II muscle fibers that they innervate (Behm & Sale, 1993; Henneman, Somjen, & Capenter, 1965). This increase in large motor unit activation will occur even if the athlete is unable to physically increase the velocity of the movement, as the intent will cause increased neural activation and an increase in rate coding, the frequency at which signals are sent to the motor neuron, that can lead to temporal summation and further recruitment of motor units (Zatsiorsky & Kraemer, 2006).

A potential result of performing exercises with maximal intended velocity is an increase in power output both acutely and over a training period. Since power equals force multiplied by velocity, increasing the velocity will increase the power output of the exercise without needing to increase or decrease the load if one is capable of doing so. It has been reported that training at the load that maximizes power output leads to superior increases in power output as compared to other training means (Kaneko, et al., 1983; Wilson et al., 1993). Therefore, it can be postulated that further increasing the power output of an exercise would lead to even greater increases in power over time. Rate of force development (RFD) is the rate of the rise in contractile force during the early phase of an action (Aagaard, et al., 2002). RFD is important for sports because while it can take over 300ms to reach maximum force output, many athletic movements occur in under 250ms. Resistance training, especially when performed with maximal intended velocity, can increase RFD up to 68.7% above baseline (Young & Bilby, 1993).

It has also been established in the literature that instantaneous feedback can result in superior performance both acutely and over a training period (Figoni & Morris, 1984; Kellis & Baltzopoulos, 1996; Kilduski & Rice, 2003; Randell, et al., 2011). This is relevant because most measurement devices used in VBT allow the athlete to see their performance measurement either mid-set or post-set. Instant knowledge of results may not increase results in every athlete, as only those who are already intrinsically motivated have the potential to increase performance based upon a target velocity measurement.

**Significance of the Study**

While traditional periodization methods are effective, they may not be optimal in many situations (Kraemer & Fleck, 2007). Collegiate strength and conditioning coaches are often faced with the challenge of developing a large group of athlete's physical qualities over periods of as short as six weeks, often after a season when the athlete may have only training once per week or less. In this situation, it may be impossible to determine and individualize the appropriate training volume for each individual athlete. Velocity-based training may allow a coach to safely, effectively, and efficiently adjust training volumes for each athlete even in a large group setting.

Although studies comparing auto-regulatory methods to traditional programming have been conducted, such as with APRE and flexible periodization, there have been no studies comparing the effectiveness of VBT to traditional methods. This study will evaluate whether VBT is a viable auto-regulatory method alternative to traditional programming. If shown to be more effective that traditional methods, VBT can be a very efficient, timely, and fairly cost effective method of ensuring optimal training sessions for collegiate athletes.

**Purpose of the Study**

The purpose of this study was to determine the effect of VBT as a form of auto-regulation on strength and power metrics in collegiate athletes. Traditional methods of periodization are often not an optimal strategy in a collegiate athletics setting. Auto-regulation, especially VBT, may be a more effective strategy as it allows for instant adjustments to be made based upon measurable metrics made available instantaneously. The study was conducted by matching pairs of Western Washington University varsity athletes within each team according to relative strength on back squat and bench press, and then randomly assigning members of each pair to either a traditional periodization group or an experimental group. This was done to eliminate the effect of ability and experience on the study results. The only difference between the groups was that the experimental group used velocity measurements to dictate the number of sets, and therefore training volume, completed in the bench press and squat exercises during each session, while the traditional group used a fixed volume program in which each session's volume was predetermined. All other exercises and training means applied to the groups were identical. Maximal strength tests were conducted on the bench press and squat both prior to and after completion of the training period. Peak power and RFD were measured though vertical jump testing on a force plate.

**Statement of Hypothesis**

The hypothesis was that the experimental group using VBT to regulate training volume will show superior increases in bench press and squat maximal strength, as well as lower body power in the vertical jump, as compared to traditional fixed volume based programming.

**Limitations of the Study**

1. Subjects were limited to NCAA Division II softball players in the pre-season phase of the year.
2. Accurate use of VBT requires athlete's gives maximal effort during concentric portion of lifts.

3. The use of VBT was limited to bench press and squat exercises.
4. No blinding of the protocol existed in the study, as both the researchers and the subjects were aware of which group each subject was in.

**Definition of Terms**

*Auto-regulation*: Method of training that allows for daily adjustment of training to match athlete's readiness levels (Kraemer & Fleck, 2007)

*Auto-regulatory Progressive Resistance Exercise (APRE):* Form of auto-regulation in which intra- and inter-session loads are partially determined by performance of preceding sets (Mann, Thyfault, Ivey, & Sayers, 2010).

*Flexible Periodization:* Form of auto-regulation that uses daily readiness tests to adjust training according to a pre-planned flexible microcycle (Kraemer & Fleck, 2007).

*Force-velocity curve:* Also known as strength-velocity curve. The graphical representation of the load-velocity relationship (Jovanovic & Flanagan, 2014).

*Heart Rate Variability (HRV):* Method of auto-regulation that determines readiness through the comparison of heart rate variability during a training period to that of a baseline (Makivic, Nikic, & Willis, 2013).

*Henneman's size principle:* Principle that establishes the order in which motor units and muscle fibers types are activated (Henneman, Somjen, & Capenter, 1965; Mendell, 2005).

*Instantaneous Feedback:* Quantitative or qualitative knowledge of performance results either during or immediately following performance of an exercise (Kilduski & Rice, 2003; Randell, et al., 2011).

*Load-Velocity relationship:* Velocity decreases as external load increases (Cronin, McNair, & Marshall, 2003).

*Maximal intended velocity:* Performing an exercise, regardless of load, with the intent to move as quickly as possible (Behm & Sale, 1993). May also be termed compensatory acceleration (Jones, et al., 1999).

*Mean velocity:* Also termed average velocity. Mean velocity recorded across all time intervals of a movement (Jovanovic & Flanagan, 2014)

*Microcycle:* Shortest unit of time used in periodization models. Typically 7-10 days in length (Baechle & Earle, 2008)

*Peak velocity:* Highest recorded velocity during a specific time interval of a movement (Jovanovic & Flanagan, 2014)

*Periodization:* Organized phases, or blocks, with systemic variations in specificity, intensity, and volume of training (Baechle & Earle, 2008).

*Rate of Force Development (RFD):* Rate of the rise in contractile forces during the early phase of an action (Aagaard, et al., 2002)

*Rating of Perceived Exertion (RPE):* Method of auto-regulation that uses a numbered scale that allows an athlete to select the difficulty level of an exercise (ACSM, 2013).

*Specificity:* Degree to which the exercise(s) included in a program replicate the actions involved in the chosen sport (Baechle & Earle, 2008).

*Triphasic muscle activation:* Pattern of activation observed in muscles during dynamic movements (Brown & Cooke, 1981)

*Velocity Based Training (VBT):* The use of velocity measurement for determination of sets, reps, and/or load (Jovanovic & Flanagan, 2014)

# Chapter II

## Review of Literature

### Fundamentals of Exercise Programming

Strength training is a stimulus for inducing increases in muscular size, strength, and power. Acute training variables that are typically considered in strength training program design include: intensity or load, number of repetitions and sets, exercise type and order, and rest between sets (Jovanovic & Flanagan, 2014). The magnitude and type of physiological adaptation can be affected by the manipulation of these variables. Two of the fundamentals of exercise programming are overload and progression, together referred to as progressive overload. According the National Strength and Conditioning Association (NSCA), overload is defined as assigning a workout of greater intensity or volume than the athlete is accustomed to (Baechle & Earle, 2008). This overload is necessary to stimulate adaptation. Because of the need for overload, a key factor in programming is specificity. The SAID acronym, which stands for Specific Adaptation to Imposed Demands, states that adaptation is dictated by the type of demands imposed upon the athlete. Since an athlete can only adapt to a certain amount of stress over a given time period, it is essential for the demands of training to reflect the demands of the sport in order to achieve carryover from training to sport performance. For overload to continue to occur, progression must be applied to training intensity and/or training volume. One or more training variables must increase over time to continue producing increasing levels of performance.

Out of the principle of progressive overload came periodization. To avoid overtraining and promote long term performance improvements a preplanned program including systematic variations in specificity, intensity, and volume among other program variables organized into periods, phases, or blocks is required (Baechle & Earle, 2008). A macrocycle typically refers to an entire training year, and is the largest categorization. Multiple mesocycles, each lasting two weeks to several months, make up a macrocycle. Each mesocycle consists of two or more microcycles, which are the smallest categorization and typically last one week, but may last up to four weeks. The concept of periodization was developed in the Soviet Union by Matveyev in the 1960's and was later adopted by American sport and exercise scientists into what has become known as western, or linear, periodization. The base of linear periodization is five blocks, or periods, performed in sequence: hypertrophy and muscular endurance, basic strength, strength and power, peaking, and active rest. Each block is several weeks in duration, with the earlier blocks having longer durations. Another common form of periodization is undulating, or nonlinear. In this model, the training stimulus either changes week-to-week (weekly undulating), or daily (daily undulating). For example, instead of progressing through hypertrophy, basic strength, and power blocks, an athlete with a daily undulating routine may perform a hypertrophy workout on Monday, basic strength workout on Tuesday, and a power workout on Friday. Undulating periodization can progress through blocks similar to those seen in linear periodization. With this model, the main objective of the block will comprise a majority of the workouts, while other workouts will be done to maintain capabilities and/or support the main objective. For example, in a power phase, daily undulation may have the individual perform a power-oriented workout on Monday and Friday, and a max strength session on Wednesday. Similar progression would be used with both linear and undulating models, the difference being whether physical qualities are being developed consecutively or simultaneously. Another characterization of periodization is concurrent periodization, in which multiple training goals are developed simultaneously over the training period. The goals can be addressed over a microcycle, such as in undulating periodization, or within a single day's session, as with the Tier System (Kenn, 2003).

Concurrent periodization models can still progress through blocks, with the main objective of the block comprising a majority of the workouts, and other workouts done to maintain capabilities and/or support the main objective. For example, in a power phase, daily undulation may have the individual perform a power-oriented workout on Monday and Friday, and a max strength session on Wednesday.

**Limitations of traditional programming**

While traditional periodization methods are effective for increasing strength and power, there are some limitations that are inherent with the use of these models (Kraemer & Fleck, 2007). One limitation is that, in a collegiate setting, there are many periods throughout the year when strength coaches are not permitted to train varsity athletes. When athletes come back from these breaks, it is a challenge to determine appropriate loads and volumes, as abilities may have decreased due to detraining. Some coaches will use a training maximum, a percentage of the most recently tested 1RM, but this method may not be accurate since athletes may retain or lose strength and power at differing rates depending on training status, activity over the break, and other factors. Another option is to retest 1RM's upon return from break. The downside to this is twofold. Not only does testing maximal strength after a period of inactivity expose the athlete to a greater injury risk, but when the period from training is only eight weeks long losing a second week for testing can have a large impact on the physical development of the athletes. Another downside of traditional percentage-based periodization is that athletes may increase their 1RM's at different rates.

Whereas a senior with five years training experience may be fortunate to add 10 lbs to his/her 1RM over six weeks, a freshman in his/her first year of structured training may see 1RM's increase by 10lbs per week for the first few months of training. Unless maximal testing is conducted weekly or semi-weekly, the freshman's strength and work capacity gains may outpace the periodization plan, leaving him/her to work below the prescribed percentages and/or training volume and prevent optimal results. In summary, traditional percentage based periodization models are effective for increasing strength and power but have some limitations that may, especially in a collegiate setting, negatively affect results due to potential inaccuracy of maximums.

While many of these challenges, such as breaks in training and differing rates of progress, are unavoidable, there are ways to mitigate the potential negative effects on an athlete's progress. Auto-regulation, or the adjustment of training demands as determined by readiness tests, allows coaches to more accurately determine and individualize the necessary load or volume for optimal progress. Rather than assigning a training max that may or may not be accurate after a break period, a coach could use a metric such as mean velocity to determine the appropriate load for the athlete without conducting a maximal test. Another example would be that depending on readiness, the optimal volume for the day may differ from what has been programmed. A coach can may be able to use intra-session auto-regulatory methods to assess the athletes work capacity for that session and determine the appropriate training volume.

**Benefits of auto-regulation**

Auto-regulation refers to adjustments in programming that are determined by the results of one or more readiness tests. Auto-regulation, if properly implemented, can allow a coach or athlete to optimize training based upon the athlete's readiness for training on a particular day and to ensure overtraining is avoided (Kraemer & Fleck, 2007). There are many ways to implement this programming technique, with each having its own strengths and weaknesses depending on the situation. With all methods, a commonality is the requirement that the tests or methods being used to evaluate readiness are accurate and reliable across time so that the present day's or week's results can be compared to a baseline. If the tests cannot be compared across time it cannot be ensured that the athlete's physical state is progressing.

**Flexible nonlinear periodization**

Flexible nonlinear periodization is a method of auto-regulation that utilizes a nonlinear, or daily undulating, model in which every training day in a given microcycle has a different training focus. At the beginning of each session the athletes readiness level is evaluated using a predetermined test, such as the vertical jump, and if the athlete scores lower than what is determined to be an acceptable level, then the workout for the day is switched to a less intensive workout. The coach would then switch the previously scheduled day to a later date in the 7-10 day microcycle (Kraemer & Fleck, 2007). This method can allow a coach to meet all the training objectives for a given microcycle while adjusting for daily fluctuations in readiness due to external factors. A disadvantage to this method is that if the athlete has a lowered readiness for a longer period of time due to illness, intense sport practice, or late nights studying for midterms at some point during the microcycle, he/she will still need to train through the more intense workouts despite their lowered readiness unless further adjustments to the program are made.

**Auto-regulatory Progressive Resistance Exercise**

Auto-regulatory Progressive Resistance Exercise (APRE) has its roots in the work of Captain Thomas DeLorme with the rehabilitation of femoral fractures. After noticing that endurance exercises such as cycling failed to improve strength and power during return from injury, which prevented soldiers from returning to the field in a timely manner, he began to examine the effect that resistance training could have on recovery time. In the 1950's, DeLorme created a protocol consisting of 2 sets of 10 repetitions with a third set continuing until failure. The next session's weight would be based upon the number of reps completed during the third set. This method was furthered by Knight in the 1970's into daily adjustable progressive resistance exercise (Verkhoshansky & Siff, 2009). He added a fourth set to failure as well as creating an adjustment chart. With this method the number of repetitions completed in the third set determined the load for the fourth set. In 1985, a six-repetition protocol was added in which the load was increased each set until the third set, after which the number of repetitions determined the load for the fourth set. Later, Siff and Verkhoshansky (2009) introduced the APRE method, in which a three rep protocol was added in addition to the ten and six rep protocols of Knight's method.

APRE may be more effective at increasing strength than linear periodization. Mann, Thyfault, Ivey, and Sayers (2010) reported on the effect of APRE vs traditional linear periodization on strength improvement in college athletes. Subjects consisted of 23 Division I football players with similar ages and training ages of 2.65 ± 0.8 years. All subjects had previously experienced linear periodization programs. For the study, the linear periodization group consisted of 11 athletes during the 2004 offseason, while the APRE group consisted of 12 athletes during the 2005 offseason. While the years differed, the training took place at the same time of the year, and was conducted by the same coaching staff. Both programs were for a period of six weeks. The APRE group used the 10RM, 6RM, and the 3RM protocols over the course of the six weeks. Only the 6RM protocol was described by the authors as they say it was the one used for the majority of the program. In set one, the athlete performed 10 repetitions at 50% of anticipated 6RM, the second set was performed with 6 repetitions at 75% of anticipated 6RM, and the third set consisted of as many repetitions as possible at 100% of anticipated 6RM until failure. During the fourth set, repetitions were performed until failure, and determined the load for the following week. The linear periodization group began with sets of 8 at 70% 1RM and progressed to a maximal test in week six. No other differences in the programming existed between the two groups. The authors found significant increases in bench press 1RM strength, estimated squat strength, and bench press endurance in the APRE group over the linear periodization group. This finding indicates that at least in the short term, an auto-regulatory program such as APRE can result in greater strength gains than a traditional resistance program.

### Rating of Perceived Exertion

Rating of Perceived Exertion (RPE) is a method that allows the athlete to modify load, volume, or a combination of the two depending on how difficult a movement feels. This method is often used with aerobic exercise, especially during cardiac rehab, but can also be applied to strength and power training. With this method the athlete rates the difficulty, often with a scale of 1-10 OMNI scale, though sometimes 6-20 Borg scale, and modifies variables according to a predetermined adjustment protocol (American College of Sports Medicine, 2013). The major requirement of this method that makes it difficult for implementation in a collegiate setting is that the athlete must be able to accurately and reliably assess the difficulty level of the exercise. If incorrectly assessed, the adjustment will not correspond with the athlete's readiness level. The athlete must have the complete trust of the coach for this method to work, as both athletes that are looking to avoid work and report a higher RPE and those that desire to work harder and report a lower RPE will cause incorrect adjustment that may lead to increased injury risk and/or decreased results. Another limitation is that RPE may not be accurate when applied to dynamic effort work where a lighter load is used with maximal intended velocity. When using submaximal loads it may not be possible to accurately assess effort level.

**Heart Rate Variability**

The way the cardiovascular system responds to stress can be monitored through measurement of changes caused by the autonomic nervous system (Makivic, Nikic, & Willis, 2013). The sympathetic and parasympathetic nervous systems regulate heart rate with consistency of the time between heart beats being determined by the balance between these two systems, termed heart rate variability (HRV). With modern technology, small devices can be worn by an athlete to measure variations in the R-R intervals, the interval between the peaks of the QRS complexes, of each heartbeat. During exercise, the R-R interval time becomes shorter and more consistent due to sympathetic nervous system dominance, and longer and more varied during rest with parasympathetic dominance. With this knowledge, training can be regulated in several ways by the time it takes for the athlete to return to a high level of variability (parasympathetic dominance), which indicates that the athlete has sufficiently recovered. Morales et al. (2014) reported on the use of HRV in monitoring stress and recovery of Judo athletes. Fourteen national level male Judo players participated in the four week study, with an average age of 22.85 years. They were divided into high training load or moderate training load groups with no significant differences in height, weight, or age between the groups. HRV was recorded at the beginning of the testing session using a Polar S810 cardiotachometer and coded transmitter. Strength testing also took place before and after the four-week training period, with bench press 1RM and power testing and isometric strength on both hands using a hand-grip exercise with a digital dynamometer. During the four-week training period, the players participated in strength training, Judo technique, endurance training, and Judo free practice multiple times per week. The high training load group completed eight session per week with limited recovery while the moderate training load group completed only three sessions per week. While there were no differences in HRV variables, stress or recovery variables, or strength variables between the two groups during pretesting, the high training load group scored lower in all categories during post testing. The authors propose that these decreases were a result of incomplete recovery caused by the high training load. These findings indicate that HRV may be a viable method of auto-regulating training, as if an athlete scored much lower than his baseline marks prior to a session, adjustments could be made for that day. HRV could also be used to determine the optimal training load for the athlete and their specific training schedule by adjusting training variables over time to ensure complete recovery between sessions.

**Velocity-Based Training**

Velocity-Based Training (VBT) is a form of auto-regulation that uses velocity measurements to determine training load, volume, frequency, and other factors (Jovanovic & Flanagan, 2014). The most important of the variables influencing strength adaptations is generally acknowledged to be to be exercise intensity or load, typically identified and programmed through the use of relative loads or percentages based off of a one-repetition max (1RM). A 1RM is traditionally determined through direct measurement or the use of multi-repetition maximum and an estimating equation, and traditional strength training relies on these percentages to create periodized programs. Several shortcomings exist with the use of percentage-based training in a practical setting. Directly measuring 1RM can be dangerous with low training-age athletes such as college freshman due to incorrect technique, can be very time consuming, and impractical for large groups that cannot be closely watched by a coach or supervisor. Also, the 1RM of low training-age athletes may change very rapidly as they progress through a program. Unless very frequent retesting is conducted, which may present injury risks and complicate periodization plans, the athletes may not realize their full potential adaptations due to completing much of the training period with incorrect percentages based on an outdated 1RM.

Velocity measurement can be used to predict 1RM through the load-velocity relationship. Jidovtseff et al. (2011) analyzed 112 subjects, 90 male and 22 female, who were all recreationally active and free from injury. After familiarization, subjects completed a 1RM concentric only bench press starting with the barbell 3 centimeters above the subject's nipple line. The second session approximately one week after 1RM testing consisted of velocity measurement at three-to-four increasing bench press loads. Four trials took place between 30-40% 1RM, three trials at 50, 60, and 70% 1RM, and two trials at 80, 90, and 95% 1RM. Each subject was instructed to move the bar as fast as possible without letting go of the bar. The highest velocity value for each trial was selected. The data was then charted in a graph and the trend line used to predict 1RM. The correlation to 1RM for the study was $r = 0.98$, indicating near perfect relationship. While this study reports that velocity is a valid way to estimate 1RM there are some limitations about the application of the findings to the practical setting. The first limitation is the number of trials necessary to predict 1RM. In a practical setting, time is often very limited, and a prolonged protocol such as this may be unfeasible in many situations. The largest limitation is that the bench press was measured using a concentric only movement, whereas typically most exercises such as the bench press are performed with an eccentric component prior to the concentric action. These findings may not apply if a full countermovement bench press is performed, due to influence from stored elastic energy and the SSC (Newton, et al., 1997).

Velocity measurement can also be used to create a load-velocity profile for an athlete in a particular exercise. Jovanovic and Flanagan (2014) describe a method where the athlete performs repetitions at a number of predetermined loads across the spectrum of their 1RM for the exercise. As with the method to predict 1RM, it has been established that concentric velocity decreases as external load increases (Cronin, McNair, & Marshall, 2003). The authors recommend measuring average velocity of four-to-six increasing intensities ranging from 30-85% of actual or estimated 1RM. They recommend three minutes of passive recovery between trials. They also recommend a spread of at least 0.5 m/s between the lightest and heaviest loads, and to perform three repetitions with lighter loads (velocity > 1 m/s), two repetitions with moderate loads (0.65-1 m/s), and one repetition with heavy loads (< 0.65m/s). The highest velocity at each tested load should be recorded and included in analysis. The athlete must be instructed to perform the exercise with maximal velocity and should be monitored by a qualified coach to ensure that technique is not altered.

When measuring velocity during non-ballistic movements such as the squat and bench press, it is recommended to use average velocity as a form of measurement and not peak velocity. Two primary reasons for this are average velocity better represents the subject's ability over the entire range of motion and average velocity during the concentric phase decreases linearly with increasing load, making analysis and trends easier to process (Jidovtseff, Harris, Crielaard, & Cronin, 2011).

Mann has used VBT with his athletes in several forms (Mann, 2013). All variations of VBT used by Mann are based on the dynamic effort method of lifting. This method is used to increase power output and is executed by lifting a submaximal weight with maximum velocity to ensure greatest possible recruitment of motor units despite the submaximal load (Zatsiorsky & Kraemer, 2006). With the ascending/descending method, a weight is chosen for the first set that the coach believes will fall within the chosen velocity range for the day. The weight is adjusted for each subsequent set, if necessary, to stay within the chosen velocity range. For example, if the chosen range is 0.8-1.0 m/s and the athlete's three reps are 0.77, 0.8, and 0.75 m/s then the weight would be reduced for the following set in an attempt to stay within the prescribed 0.8-1.0 m/s zone. Another method is to perform a predetermined number of sets at a chosen weight with number of repetitions per set varied, depending on velocity readings. This requires a device that gives immediate feedback during the set, as the athlete would continue each set until the velocity drops below 90% of their best reading. A third method is to have a predetermined weight and repetitions, but continue completing sets until the velocity drops below 90% of the best reading for the day. For example, if the athlete records a repetition at 1.0 m/s during their $3^{rd}$ set and in the $7^{th}$ set records a 0.88 m/s repetition, the exercise would be terminated.

In summary, VBT is an auto-regulatory method that can be implemented in a number of ways depending on the goal. VBT can be especially valuable for regulating training volume and ensuring that the quality of work remains high, as load, repetitions, and sets can be adjusted depending of the velocity readout. Another benefit is that implementation of VBT is typically relatively straightforward and user friendly due to the minimal equipment necessary for measurement. This makes it valuable for the collegiate or team setting as the athletes that would be using the devices will not require much additional instruction before being able to use VBT.

**Factors affecting velocity-based training**

**Maximal intended velocity encouraged**

One benefit of VBT is that maximal concentric velocity is encouraged. Henneman's Size Principle states that a given muscle contains numerous motor neurons, which innervate dozens to hundreds of muscle fibers within the muscle (Mendell, 2005). Henneman determined that large motor neurons innervate Type II muscle fibers that are lacking in mitochondrial ATPase, and Type I fibers that are rich in mitochondrial ATPase and have high access to capillaries are innervated by smaller motor neurons. An early study by Henneman, Somjen, and Carpenter (1965) found that there is a "highly significant correlation between threshold or excitability of individual neurons and the size of the impulses recorded from their axons". These finding show that motor units are recruited in order of smallest to largest, or slow-twitch Type I fibers to fast-twitch Type II fibers. The fibers are recruited as needed, with lower intensity exercise only recruiting the smaller, slower muscle units and fibers. High velocity movements may necessitate the activation of fast twitch motor units due to the required contraction velocity. Performing an exercise with maximal intended velocity would ensure the greatest recruitment of Type II fibers during the action which would be beneficial for power athletes who have a very limited window to apply the maximal amount of force within their sporting actions.

Research indicates that performing an exercise, regardless of load, with maximal intended velocity can lead to superior increases in strength and power as compared to exercises performed with identical loads at slower speeds. In a landmark study, Behm and Sale (1993) trained 16 subjects, eight men and eight women, three days/week for 16 weeks in ballistic ankle dorsiflexion movements. One limb was trained against an unmovable resistance that resulted in the contraction being isometric in nature, and the other limb was trained with resistance allowing a high velocity isokinetic movement up to 300 deg/s. The authors found that training produced the same high velocity specific adaptations in both limbs. Both limbs showed similar increases in voluntary isometric rate of torque development, relaxation, and evoked tetanus rate of torque development. These results suggest that the intent to move at a high velocity may be as important as the actual velocity of the movement. Increasing the velocity at which a given load moves increases the peak force during the movement, which can lead to greater strength increases. This has enormous implications for training and programming as it indicates that adaptations consistent with both high velocity training and high load training can be reached simultaneously.

Another term for maximal intended velocity is compensatory acceleration. Jones, Hunter, Fleisig, Escamilla, Lemak (Jones, Hunter, Fleisig, Emscamilla, & Lemak, 1999) examined the effects of compensatory acceleration on upper body strength and power in collegiate athletes. The authors looked at 30 NCAA Division-IAA football players over a period of 14 weeks. The subjects were divided into either the experimental group, which was instructed to perform each repetition with maximal velocity, or the control group which was not given instruction regarding bar velocity. Each week of training consisted of heavy and light days for both the upper and lower body. Testing was conducted on bench press 1RM, seated 12 lb medicine ball press for distance, and a plyometric pushup on a force platform. The authors reported that the experimental group increased significantly more than the control group in both bench press 1RM (9.4 vs 2.8%) and seated medicine ball throw for distance (8.6 vs 3.8%). No statistically significant differences were seen with the plyometric pushup test. However, the experimental group showed the amortization phase to decrease double that of the control group, and power increased three times as much as the control group. The control group had a very slight increase in peak force versus the experimental group, which may indicate that maximal intended velocity has a greater impact on power output and speed of contraction than on absolute force production.

Gonzalez-Badillo, Rodriguez-Rosell, Sanchez-Medina, Gorostiaga, and Pareja-Blanco (2014) reported that maximal intended velocity resulted in greater bench press gains than slower training. In this study, 20 physically active sport science students with 2-4 years recreational experience with the bench press exercise participated as subjects. The subjects trained three days per week for six weeks with half the subjects in a maximal velocity group and the other half in a half velocity group. A linear velocity transducer was used to ensure subjects stayed in the correct velocity ranges, with load being adjusted if necessary. The authors found after the six weeks that the maximal intended velocity group had greater increases in 1RM strength (18.2 vs 9.7%) and velocity developed against all, light, and heavy loads (20.8 vs 10%; 11.5 vs 4.5%; 36.2 vs 17.3%).

Pareja-Blanco, Rodriguez-Rosell, Sanchez-Medina, Gorostiaga, and Gonzalez-Badillo (2014) used a similar structure in their study examining the effects velocity of the full squat exercise. Twenty-one men with an average age of 23.3 participated in the study, with training taking place over a six week period. All subjects were physically active sports science students with resistance training experience ranging from 1.5 to 4 years, and were familiar with the full squat exercise. In the three weeks prior to the study, five familiarization sessions took place with the purpose of emphasizing correct technique and execution of the full squat exercise, as well as familiarizing the subjects with the two velocity variations. Subjects were randomly assigned to either a maximal intended velocity group or a half-speed velocity group. A linear position transducer was used to ensure the subjects stayed in their assigned velocity ranges. Subjects in both groups progressed from 60-80% 1RM during the study, with the only difference being the intended velocity during the exercise. No significant differences were found between the groups for any of the tested measures prior to training. Post training the maximal intended velocity group showed greater improvements over the half velocity group in counter movement jump (8.9 vs 2.4%), full squat 1RM (18 vs 9.7%), velocity developed against all, light, and heavy loads (14.6 vs 7.5%; 10.9 vs 5.0%; 17.6 vs 13.1%). The authors of both these papers concluded that the results indicate that resistance training intensity is more than simply the external load being moved, and that the velocity of the movement at a given load can influence the training effect and provide superior neuromuscular adaptations as compared to movements performed at less than maximal velocity.

Padulo, Minogna, Mignardi, Tonni, and D'Ottavio (2012) also investigated the effect of different pushing speeds on muscular strength in the bench press. The program lasted three weeks with training sessions twice a week at 85% 1RM on bench press. Participants were 20 resistance trained subjects with over 18 years training experience . They were divided into two groups, one performed the bench press at 80-100%, while being instructed to give maximal effort on each rep, of the maximal speed determined in pretesting while the other group performed the exercise at a self selected speed. The authors reported significantly superior increases for the maximal intended velocity group in maximal strength (10.20 vs 0.17%) and peak velocity (2.22 vs 0.11%) versus the self selected velocity group. The findings indicate that maximal intended velocity can have a large impact on the effects of reistance training even in those with extensive training experience.

These studies support the finding by Behm and Sale that the intent to move at a high velocity may be as important as the actual velocity of the movement. One reason for the superior results seen in maximal intended velocity training could be that increasing the velocity at which a given load moves increases the power output of that set versus conventional velocity exercise.

**Effect of power training**

Power can be defined as the force applied multiplied by the velocity of movement, and it is essential for most athletes to have a high power output in order to be successful in their sport at higher levels. The force-velocity relationship of muscle was identified by Hill in 1938, and states that during dynamic contractions, movement velocity will decrease as external load increases. Hill found that for single joint muscles, maximum peak power output was achieved at 30-35% of maximal isometric strength. Since then, the resistance at which power output is maximized has been widely studied across a variety of populations and exercises.

Kawamori et al. (2005) reported peak and average power during the hang power clean in NCAA Dvision II football players, weightlifters, rugby player, basketball player, bobsledder, and recreationally trained men to occur at 70% 1RM. No significant difference existed in peak power between 70 % and 50, 60, 80, or 90% 1RM, and no significant difference was seen in average power between 70% and 40, 50, 60, 80, or 90% 1RM. Cormie, McCaulley, Triplett, and McBride (2007) examined 12 NCAA Division I football players, sprinters, and long jumpers for the optimal load for maximal power output during the jump squat, squat, and power clean exercises. The authors found that peak power was maximized in the power clean at 80% 1RM, and back squat at 56% 1RM, though there was no significant difference from 0% to 85% 1RM for the squat. For the leg press, peak power has been reported between 56-78% of 1RM in untrained women (Thomas, Fiatarone, & Fielding, 1996). For the bench press throw, maximal power was reached in professional rugby players at 30% in one study, and in another at 55%, with an effective range of 46-62% 1RM (Bevan, et al., 2010; Baker, Nance, & Moore, 2001). The squat jump is one of the most commonly studied power exercises, and the percentages used typically are based off of back squat 1RM. Peak power occurs at 0%1RM, or bodyweight, in a variety of populations including professional rugby players, Division I athletes, and untrained individuals (Bevan et al., 2010; Cormie, McCaulley, Triplett, & McBride, 2007; Cormie, McBride, & McCaulley, 2008).

Multiple studies have shown that training at the load that optimizes power output for a given exercise leads to greater increases in power output than other loads. Kaneko, Fuchimoto, Toji, and Suei (1983) examined the training effects of different loads on power output during single joint elbow flexor movements. Twenty untrained males aged 18-22 were divided into four groups of variously loaded concentric contractions. The groups were unloaded, 0%, 60% or 100%. The percentages were based off of a 90 deg isometric arm flexor maximum with 0%, 30% and 60% being isotonic, and 100% being isometric. Using a special apparatus, the subjects performed the assigned contractions with maximum effort 10 times per day, three days a week, for 12 weeks. No significant differences in isometric force, velocity, or power were observed pre-training. After 12 weeks, the authors reported that maximum power increased in all groups, but significantly greater in the 30% group. As previous research indicates that for single joint movements maximum power output occurs at 30-35% of maximum isometric strength, these findings suggest that training at the load which maximizes power output leads to significantly greater increases in power output than other loads.

Research has also been conducted on the effect of training at the load that maximizes peak power in a multi joint exercise. Wilson, Newton, Murphy, and Humphries (1993) examined fifty-five subjects with at least one year resistance training experience and who could perform a half-squat exercise with at least bodyweight. These subjects were randomly assigned to one of four groups: traditional weight training, plyometric training, maximal power output, or a control group with no training. Tests were conducted prior to the training period, at the five week point, and at the 10 week point, and consisted of a 30m sprint, vertical jump with and without countermovement, peak power during a six second cycle test, and peak torque during an isokinetic leg extension. The authors reported significant increases for the maximal power group over the groups in the countermovement and non-countermovement jumps, and a non-significant increase over the other groups in the 30m sprint. In all, the maximal power group showed statistically significant improvement in both jumps, isokinetic leg extension torque, six second cycle power, and was near statistical significance in the 30m sprint. Weight training alone only showed significant improvements in both jumps and cycling power, and plyometrics only showed significant improvement in the countermovement jump. The results indicate that training at the load that maximizes power output is the most effective form of training for enhancing performance of dynamic exercises. This is very important for the training of athletes as jumps and sprints are essential movements for most sports.

It is apparent from these studies that training at the load that maximizes power output is the most effective for training power athletes. It would stand to reason that if power output could be instantly increased during a given exercise than the athlete could see greater results than if they performed the exercise at lower power output level. As power equals force multiplied by velocity, training with maximal intended velocity resulting in increased velocity at a given load will result in a higher power output than a non-maximal velocity repetition at a given load. This would increase the peak power level for the individual during the given exercise and should lead to increased power output.

**Rate of force development**

Rate of force development (RFD) refers to the rate of the rise in contractile force during the early phase of an action (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Pulsen, 2002). In isolated muscle preparation, RFD can be calculated by looking at the slope of the force-time curve. RFD has special significance for sports as, while it takes over 300ms for maximum force to be generated, many athletic movements take place in under 250 ms. As this timeframe does not allow for maximum levels of force to be reached, it is essential that athletes attempt to develop their RFD in order to maximize their physical performance on the playing field. Aaagaard, Simonsen, Andersen, Magnusson, and Dyhre-Poulsen (2002) examined the effect of resistance training on RFD. Fifteen untrained male subjects participated. Progressive heavy resistance training was performed for a total of 38 sessions over 14 weeks. Four to five sets at 3RM-10RM loads were completed for hack squats, incline leg press, isolated knee extensions, hamstring curls, and seated calf raises over the training period. The authors reported significant increases in contractile RFD at the completion of the straining period indicating that resistance training may be a viable method to increase RFD. This study, however, did not compare the effects of using various velocities on intent on RFD development.

An earlier study by Young and Bilby (1993) examined the effect of voluntary effort to influence speed of contraction on strength and power. Eighteen untrained male college students volunteered for the study and were assigned to either a fast group or a slow group. The subjects performed barbell half-squats and were required to lift four sets to failure in the 8-12 repetition range three times per week for seven and a half weeks. The fast group was instructed to move with maximal intended concentric velocity while the slow group was told to compete each rep “slow and controlled”. Post-testing after the conclusion of the study showed that the fast group saw a non-significant 68.7% increase in maximal RFD versus only 23.5% for the slow group. These findings are consistent with the previous information presented by Behm and Sale and others that maximal intended velocity likely leads to greater motor unit recruitment and greater power and strength gains over slower movements.

**Triphasic pattern activation and braking forces**

EMG measurements of muscles during explosive voluntary movement shows a “triphasic” pattern of muscle activation. This pattern is characterized by agonist muscle activation, followed by a burst from the antagonist, followed by another burst from the agonist. For example during a concentric only pushup there will be burst from the triceps, followed by a burst from the biceps near the end of the movement, and then concluded by another burst from the triceps. Brown and Cooke examined this phenomena in elbow flexion/extension movements under three conditions. The subjects were instructed to either make the movements as accurately as possible and not over or under shoot the target, as quickly as possible where overshooting the target was allowed, or as fast and as accurate as possible where they must go as fast as they can without sacrificing accuracy. Brown and Cooke (1981) reported that in the higher velocity movements the triphasic activation pattern was more pronounced, and that the antagonist activity occurred sooner, often overlapping the first agonist burst. They also saw that all bursts increased in magnitude as velocity increased, and that the late agonist burst happened sooner with faster movements. Also of importance, the antagonist burst was seen to occur sooner and with a shorter duration for the fast movements. The initial burst starts the movement and the antagonist causes deceleration as the end of the range of motion is approached. The second agonist burst serves to balance out the action of the antagonist.

When light and medium external loads are used during exercise, a larger than expected deceleration phase, or antagonist activation, has been observed (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010). During this final phase, the force applied by the athlete on the bar is negative as the antagonist muscles resist to stop the bar from leaving the hand/back. Because of this activation of the antagonist muscles, the concentric portion of a light-medium external load lift can be broken into propulsive and braking phases, with the propulsive phase occurring from the onset of concentric action until the antagonist activates and begins the braking phase near the end range of motion . Braking forces cease above 76 ± 7.4% 1RM (Sanchez-Medina, Perez, & Gonzalez-Badillo, 2010), and since it has been demonstrated that using maximal intended velocity can produce adaptations similar to lower load training with loads up to 85% 1RM it is possible that utilizing maximal intended velocity with loads above the braking threshold may be a way to minimize the effect of these braking forces and develop power throughout the entire range of motion. While not directly related to auto-regulation with VBT, the avoidance of braking forces may be a beneficial side effect of the maximal intended velocity that is required for VBT.

**Effect of Feedback on Performance**

Many methods of auto-regulation utilize feedback to make adjustments in programming. It has been established that instantaneous feedback in terms of knowledge of results and knowledge of performance can have a substantial positive effect on the acquisition of motor skills and athletic performance, both acutely and over a training period (Randell, Cronin, Keogh, Gill, & Pedersen, 2011). Kilduski and Rice (2003) assigned 77 adults to one of four feedback conditions: quantitative, qualitative, quantitative and qualitative, or no feedback (control group). The subjects were taught an isometric force production skill and data was collected during both skill acquisition and skill retention phases. Subjects pressed down on a load cell with maximum pressure to collect a maximum force level, then during testing were asked to press down with 40% of their previously measured maximum force. Qualitative feedback was given by voice and consisted of phrases such as “Excellent! You pressed just right!”, “Not so great. You pressed way too hard/light”, and phrases indicating results in between these two extremes. The quantitative feedback was displayed on the computer screen and showed the percentage of pressure by which the subject erred. The authors found that qualitative feedback, whether alone or with quantitative feedback resulted in superior skill acquisition.

A study by Figoni and Morris (1984) examined the effects of knowledge of results on strength and fatigue. Twenty healthy males participated, with an average age of 27 ± 4.2

years. No information on the training status of the subjects was given. The tests were administered using a Cybex II isokinetic dynamometer at approximately the same time on three consecutive days. Day one, descriptive data was collected and subject were familiarized with the equipment and protocols. On days two and three, subjects were randomly assigned to one of eight conditions balancing presentation of test speeds, right or left legs, and knowledge of results or no knowledge of results. Each subject performed slow speed tests at 15deg/s with one knee and fast speed tests at 300deg/s with the other. Tests were maximal in effort and reciprocal in nature. Two strength trials were completed before a fatigue trial. The results showed no effect on knowledge of results during the fast movements, but showed a 12% increase in strength during the slow movements. The authors hypothesize that during the fast movements the interval between the reciprocal movements was too short for the subjects to process and apply the knowledge of results. It is very possible that if a pause was present between each rep of the fast movement that the subjects would be able to process the knowledge and would see increased strength levels similar to that seen in the slow movements (Figoni & Morris, 1984).

In 1996, Kellis and Baltzopoulos conducted a study on the effect of visual feedback on maximum moment of knee extensors and flexors during resistive isokinetic eccentric exercise. 25 men with no history of musculoskeletal injury in the lower limbs and an average age of 21.9 ± 3.1 years participated. All tests were performed on a Biodex dynamometer. After warmup and familiarization each subject performed three submaximal and two maximal eccentric repetitions at both 30deg/s and 150deg/s. The range of motion was from 10deg to 90deg of knee flexion, and the testing order was randomized with a five minute rest period between each of the four test conditions. The authors found that visual feedback during each test resulted in in increased force over non-feedback in both the fast and slow conditions for both extensors and flexors. Extensor strength was 7.2% higher at 30deg/s and 6.4% higher at 150deg/s. Flexor strength was 8.7% higher at 30deg/s and 9.0% higher at 150deg/s. One reason this study found increases from knowledge of results during the fast condition while Figoni and Morris did not could be the use of eccentric action. As it has been established that eccentric action requires less neural activation as compared to concentric actions, it may be possible that the decreased neural demand during the eccentric tests allowed for the subjects to process the feedback and apply the knowledge during the tests (Westing, Cresswell, & Thorstensson, 1991).

While the studies mentioned above have examined the effects of instantaneous feedback on acute performance, much less research has been conducted on the effects of feedback on a training period. Randell, Cronin, Gill, and Pedersen (2011) investigated the effect of instantaneous performance feedback during jump squats over a six week period. Thirteen professional rugby players were randomly assigned to either feedback or non-feedback groups. No significant differences were presented between the two groups in age, height, mass, training age, or 1RM squat. Each group completed their testing at least 48 hours prior to the start of the study, and 48 hours after the completion of the training period. Testing consisted of bilateral vertical and horizontal jumps, and 30m timed sprints with split times recorded at 10m and 20m. All subjects performed similar resistance sessions 3 times/week, and completed the same conditioning sessions. Three sets of three concentric squat jumps from a knee angle of 90deg were performed in two of the three weekly sessions. Subjects in both groups were instructed to move as explosively as possible, with a pause in between each repetition to distinguish each movement. The feedback group was given visual feedback of each repetitions peak velocity in real time while the non-feedback group received no visual aid. Velocity was recorded using a linear position transducer. The feedback group saw greater superior improvements to the non-feedback group in vertical jump (4.6 vs 2.8%), horizontal jump (2.6 vs 0.5%), 10m split (1.3 vs 0.1%), 20m split (0.9 vs 0.1%), and 30m sprint time (1.4 vs -0.3%). However, the 30m sprint time was the only test to see a statistically significant difference between the two groups. The authors note that feedback resulted in a greater consistency of peak velocity during the squat jump.

This finding is important because of the findings of McBride, Triplett-McBride, Davie, and Newton on the effects of various load jump squats on the development of strength, power, and speed qualities (McBride, Triplett-McBride, Davie, & Newton, 2002). Twenty-six thletic men between 18-30 years old with an average of two to four years resistance training experience performed jump squats at either 30% or 80% of their previously determined 1RM in the squat exercise or served as a control group. Subjects were matched and assigned based upon 1RM squat to bodyweight ratio in order to ensure that the average for each group was similar. Two days of testing took place both before and after an 8 week training period during which they participated in one-on-one supervised workouts twice per week. On day one of testing, body composition, agility T-test, and 20m sprint were measured, while on day two, 1RM squat and jump squat testing was conducted. The authors found that the group that performed the jump squats at 30% saw greater increases in the tests that required high velocity, while the 80% group saw superior increases in the tests with less of a velocity requirement.

This is important because it suggests that training at a higher velocity can lead to superior increases in high velocity tasks, such as those in seen in practically all sporting actions. The finding by Randell et al. that instantaneous feedback causes a greater consistency of peak velocity indicates that, over time, the increased peak velocity compared to non-feedback groups would continue to lead to greater adaptions for high velocity movements that are vital for sport performance.

**Considerations for VBT**

One consideration about the use of VBT as a form of auto-regulation is that an athlete with low motivation may try to “cheat” the system. While most collegiate athletes are highly motivated to improve themselves physically, there are some that due to various reasons, whether it be a disagreement with the coach, disillusionment with their team, burnout, or other factors, may choose to perform an exercise with less than maximal intended velocity in order to use a lowered weight for that workout, or to complete less sets. In order to combat this issue, Mann writes that his University of Missouri football team uses a multi-level classification of athletes, with absolute strength numbers, hypertrophy needs, explosive strength, comparison to team standards, and trust of the coaches playing a role in the classification. VBT is used with the athletes in the higher levels of this program that have the trust of the coaches so the concern over misuse of VBT is low for them (Mann, 2013).

**Summary**

While it has been established that traditional periodization models can be effective in developing strength and power, these models do have limitations, in large part due to no attempt made to measure or adjust for an athlete’s readiness level (Kraemer & Fleck, 2007. Auto-regulatory methods include daily readiness tests that determine an athlete’s readiness level, and allow for adjustments to be made according to the results of the readiness test(s). These methods may be potentially more effective than traditional periodization for increasing maximal strength and power output (Kraemer & Fleck, 2007; Mann, et al., 2010; Mann, 2013, Jovanovic & Flangan, 2014; Morales, et al., 2014). Although many methods of auto-regulation exist, VBT may be especially beneficial for coaches due to the relative ease and simplicity of implementation with large or small groups, and athletes due to the encouragement of maximal intended concentric velocity, which may cause increases in maximal strength, peak velocity, peak power output, mean RFD, and reduce braking forces near full extension range of motion over submaximal velocity movement at identical loads (Behm & Sale, 1993; Young & Bilby, 1993; Jones, et al., 1999; Sanchez-Medina & Gonzalez-Badillo, 2010; Padulo, et al., 2012; Gonzalez-Badillo, et al., 2014; Parejo-Blanco, et al., 2014; Jovanovic & Flanagan, 2014).

Another potential benefit of VBT use is that it often provides instant feedback on performance via the readout on the measurement device. It has been established in the literature that knowledge of results can led to increased performance of subsequent bouts both in the same session, and over a training period (Figoni & Morris, 1984; Kellis & Baltzopoulos, 1996; Kilduski & Rice, 2003; Randell, et al., 2011). While instant knowledge of results may not improve performance for all athletes, it may benefit those who are intrinsically motivated and allow them a target performance to strive for. While a limitation of VBT is that athletes with low motivation may be able to “cheat” the system by intentionally performing an exercise at submaximal velocity, there is evidence that suggest VBT is a viable method of auto-regulation and that it may allow for superior increases in maximal strength,

# Chapter III

# Methods and Procedures

## Introduction

The purpose of this study was to determine the effect of Velocity-Based Training (VBT) as a form of auto-regulation on strength, peak power, and mean rate of force development (RFD) in collegiate athletes. Athletes were divided into two groups, with one group using traditional percentage based loading with a fixed volume on back squats and bench press, and an experimental group regulating training volume through velocity measurements on back squat and bench press. After being randomly divided into the two groups, subjects completed a six-week training program. The programs for the two groups in each sport were identical, except for the number of sets for the experimental group for back squat and bench press was variable depending on velocity measurements. Total volume was recorded during the study for comparison between the groups. Testing took place before and after the six-week training period, with maximal strength testing being conducted for back squat and bench press, and a countermovement vertical jump test conducted to measure mean RFD and power output.

The purpose of this chapter is to describe the methods and procedures used during this study. Description of subjects will be followed by design of the study, data collection procedures, measurement techniques, and data analysis.

## Description of Study Subjects

Subjects consisted of 17 varsity women’s softball players at Western Washington University All subjects who participated in the study were familiar with resistance training and were in the pre-season phases of their training year. All players had been in a periodized collegiate strength and conditioning program for at least one year prior to participation in the study to attempt to ensure that exercise technique would not be a limiting factor in the study. Because of this experience requirement, freshman athletes were excluded from the study. The Western Washington University Human Subjects Committee reviewed the study prior to data collection, and subjects gave their informed consent (Appendix A and B).

**Design of the Study**

The study took place over a six-week period during the winter academic quarter. During the six-week training period, the team completed two training sessions per week. Each session included plyometric, resistance training, and injury prevention components. In addition to training sessions, the team participated in three-to-five sport practices per week during the study. A general sample of training session structure is in appendix C. The Maximal Effort (ME), Dynamic Effort (DE), Submaximal Effort (SE), and Repetition Effort (RE) listed in the program follow the guidelines for these methods as described by Laputin and Oleshko (1982), and Zatsiorsky and Kraemer (2006). The ME method is the basic method for developing maximal absolute strength, and consists of sets of one to two repetitions at 90-100% of one-repetition maximum (1RM). The DE method primarily targets RFD and explosive strength, with sets of 1-3 repetitions at 55-80% of 1RM performed as explosively as possible to ensure maximal recruitment of motor units despite the relatively low load. The SE and RE methods are both submaximal, repetition based methods. Both methods require that the athlete reach fatigue in order to activate the maximal number of motor units, with the primary difference being the number of repetitions performed, as the SE method is four-eight repetitions at >70% and the RE method is typically 10-20 repetitions at moderate-light load. Both methods stimulate more hypertrophy as compared to the ME and DE methods due to the increased total mechanical stress and metabolite accumulation.

The experimental group used velocity to regulate the training volume for squat and bench press. Upper and lower session volume limits for bench press and back squat were set according to Prilepin's chart, which was developed by a Soviet sports scientist in the 1970's based upon his observations of Olympic weightlifters (Laputin & Oleshko, 1982).

| **Percent** | **Reps/Set** | **Optimal repetitions** | **Total repetition range** |
|---|---|---|---|
| 55-69% | 3-6 | 24 | 18-30 |
| 70-79% | 3-6 | 18 | 12-24 |
| 80-89% | 2-4 | 15 | 10-20 |
| 90%+ | 1-2 | 4 | 1-10 |

Volume was regulated by having the athlete record the highest velocity repetition in each set completed at the prescribed load. The athletes continued completing sets until either the highest velocity repetition of a set drops more than 10% from the highest mark, or the athlete reaches the established upper volume limit, whichever comes first. For example, if the athlete recorded a repetition of 0.9 m/s in his/her third set with a load of 75% 1RM, she would continue completing sets until either the highest velocity repetition in a set dropped to 0.8 m/s or lower, or the athlete reached 24 total repetitions. The exception to this is if the athlete drops below 10% of the highest repetition measured before reaching the minimum volume for the session. In this case, the athlete would continue completing sets at the prescribed load until the minimum volume was reached, at which point he/she would terminate the exercise for the day.

There was no singular training focus during this training period, as the program used during this study utilized a concurrent periodization model based off of the Tier System by

Kenn (2003). This system is catagorized by the rotation of movement patterns through the various effort methods (ME, SE, DE, RE) described previously. As displayed in the sample program in appendix D, throughout the week each movement pattern (squat, hinge, push, pull) had exercises in multiple effort methods. This allowed for simultaneous strength, power, and hypertrophy development. However, while there was no singular training focus, the emphasis during the training period was on power development.

## Data Collection Procedures

### Training session procedure

Velocity measurements were taken with a PUSH armband (PUSH, Toronto, ON, Canada). Each subject in the experimental group wore one of these armbands during training sessions on the lateral aspect of the proximal forearm, fastened just inferior to the medial and lateral epicondyles. To operate, the armband was turned on prior to the beginning of the training session and synced via Bluetooth technology with an iPod Touch (Apple, Cupertino, CA, U.S.A) on which an app provided an interface. Prior to initiating a set, an athlete would tap his/her icon on the screen and select the appropriate exercise. Once the athlete is in position to start his/her set, prior to unracking the barbell, the athlete would push the button on his/her armband to start recording. After completion of the set, the athlete would then push the button again to terminate the recording. This procedure was completed during each set of squat and bench press.

### Instrumentation

Pre-training and post-training, an AMTI OR6-6 (AMTI, Watertown, MA) force platform was used for collection of mean RFD and peak power during a countermovement jump. Vertical ground reaction force (GRF) data from countermovement jump trials were analyzed via custom-written LabVIEW software (National Instruments, Austin, TX) to determine jump height (using the impulse-momentum relationship equation), mean RFD (calculated as the slope of the line from maximum unweighting to peak force during the jump), and peak power output (calculated as the highest product of force and velocity during the jump prior to toe-off) from the data gathered during the jumps. Microsoft Excel (Microsoft Corporation, Redmond, WA), was used to find peak force during an isometric quarter-squat. Maximal strength pre-testing for the back squat by way of estimated 1RM was conducted with a Texas Power bar (Capps Welding, Irving, TX) and in a Hammer Strength HD Elite Half Rack (Life Fitness, Rosemont, IL). Bench press maximal testing was conducted with the use of a Hammer Strength HD Elite Adjustable Bench (Life Fitness, Rosemont, IL) in addition to the Half Rack and Texas Power bar.

**Measurement techniques and procedures**

Countermovement vertical jump testing took place on a force platform, prior to maximal strength testing. After a dynamic warmup, two practice jumps were allowed for familiarization with the test. After this, subjects completed three trials on the force plate. Subjects were instructed to complete the jumps with maximal effort, and attempt to avoid jumping forwards off the platform in order to ensure the maximal amount of force would be applied vertically. A Vertec apparatus (Perform Better, West Warwick, RI) was placed adjacent to the force platform to give the athletes a target to jump for, but was used for data collection or analysis. Following the vertical jump trials, peak isometric force output was determined by performing an isometric quarter-squat into a fixed barbell while standing on a force platform. After completion of the countermovement jump and isometric quarter-squat trials, estimated one repetition maximum (1RM) for the bench press was determined according to NSCA testing procedures (Baechle & Earle, 2008). A three repetition maximum was determined, from which the O'Conner formula (1RM = load*(1 + (0.025*number of repetitions)) was used to estimate the 1RM.

**Data Analysis**

A two-way mixed analysis of variance (ANOVA) was used to determine the effects of group (traditional vs. VBT) and time (pre-test vs. post-test) on the dependent variables: estimated one-repetition maximum (1RM) for bench press, peak force reached during an isometric partial squat, and mean RFD, peak power output, jump height during a countermovement vertical jump. The alpha level to determine significance was set at $p < .05$.

# Chapter IV

# Results and Discussion

## Introduction

The purpose of this study was to determine the effects of using Velocity-Based Training (VBT) to regulate resistance training volume over a six-week training period in the back squat and bench press exercises on vertical jump height, mean rate of force development (MRFD), peak power (PP), peak force during an isometric quarter-squat (PF), and bench press estimated one-repetition maximum (1RM). It was hypothesized that the experimental group using VBT to regulate training volume would experience superior increases in the dependent variables as compared to a control group using conventional fixed-volume training. This chapter presents and discusses the results of this study.

## Subject Characteristics

The study sample consisted of 17 female NCAA Division II softball players between the ages of 19 and 22 years old. All subjects were participating in a regular strength and conditioning program during the pre-season phase, and had previously been instructed to avoid additional training outside of team activities. All subjects completed the study, but two subjects did not perform the back squat exercise or participate in force plate testing, and two subjects did not perform the bench press exercise, due to previous injuries or medical restrictions. Table 1 includes subject characteristics for each group.

**Table 1: Subject characteristics**

| **Subjects** | Control N = 8 | VBT N = 9 |
|---|---|---|
| | **Mean ± SD** | |
| | **Control** | **VBT** |
| **Age (years)** | 20.67 ± 0.9 | 20.00 ± 0.9 |
| **Body Mass (kg)** | 75.86 ± 10 | 83.77 ± 25.7 |
| **Height (cm)** | 167.91 ± 3.4 | 168.91 ± 3.2 |

**Results**

No significant interaction was observed between time and group for vertical jump height ($F$ [1, 13] = 3.703, $p$ = .076, $\eta^2$ = .222). No significant main effect of time was seen for vertical jump height ($F$ [1, 13] = 13, $p$ = .079, $\eta^2$ = .218). No significant effect of group was found for vertical jump height ($F$ [1, 13] = .405, $p$ = .536, $\eta^2$ = .030). No significant interaction was observed between time and group for MRFD ($F$ [1, 13] = 1.154, $p$ = .302, $\eta^2$ = .082). No significant main effect of time was seen for MRFD ($F$ [1, 13] = .796, $p$ = .389, $\eta^2$ = .058). No significant effect of group was found for MRFD ($F$ [1, 13] = .089, $p$ = .770, $\eta^2$ = .007). No significant interaction was observed between time and group for peak power ($F$ [1, 13] = .000, $p$ = .987, $\eta^2$ = .000). A significant main effect of time was seen for peak power ($F$ [1, 13] = 4.892, $p$ = .045, $\eta^2$ = .273). No significant effect of group was found for peak power ($F$ [1, 13] = .468, $p$ = .506, $\eta^2$ = .035). No significant interaction was observed between time and group for peak force during an isometric quarter-squat ($F$ [1, 13] = .2.310, $p$ = .152, $\eta^2$ = .151). No significant main effect of time was seen for peak force ($F$ [1, 13] = .083, $p$ = .778, $\eta^2$ = .006). No significant effect of group was found for peak force ($F$ [1, 13] = .051, $p$ = .824, $\eta^2$ = .004). No significant interaction was observed between time and group for bench press 1RM t ($F$ [1, 13] = 2.310, $p$ = .152, $\eta^2$ = .151). No significant main effect of time was seen for bench press 1RM ($F$ [1, 13] = .083, $p$ = .778, $\eta^2$ = .006). No significant effect of group was found for bench press 1RM ($F$ [1, 13] = .051, $p$ = .824, $\eta^2$ = .004). Table 2 displays pre- and post-test values for all dependent variables.

**Table 2: Dependent Variables**

| | Group | Pre Value | Post Value | Percent Change |
|---|---|---|---|---|
| **Vertical Jump (cm)** | **Control** | 28.66 ± 4.5 | 30.75 ± 6.1 | 7.29% ± 7 |
| | **VBT** | 27.65 ± 6.4 | 27.64 ± 7.7 | -0.04% ± 11.3 |
| **MRFD (N/s)** | **Control** | 2472.08 ± 1084.9 | 2003.31 ± 385.7 | -18.96% ± 29 |
| | **VBT** | 2357.71 ± 1414.3 | 2401.21 ± 887.1 | 1.85% ± 37.7 |
| **Peak Power (W)** | **Control** | 3395.33 ± 553.6 | 3545.83 ± 549.3 | 4.43% ± 3.9 |
| | **VBT** | 3559.35 ± 462.4 | 3707.69 ± 337.8 | 4.17% ± 9.3 |
| **Peak Force during Isometric ¼-Squat (N)** | **Control** | 1111.04 ± 181.9 | 1058.54 ± 241.1 | -4.73% ± 10.5 |
| | **VBT** | 1067.86 ± 131.3 | 1144.89 ± 235.6 | 7.21% ± 19.6 |
| **Bench Press 1RM (kg)** | **Control** | 50.79 ± 8.6 | 51.41 ± 7.6 | 1.22% ± 6 |
| | **VBT** | 54.78 ± 18 | 56.89 ± 6.4 | 3.85% ± 7 |

Though none of the changes between groups were statistically significant, the VBT group did demonstrate superior increases in MRFD (+1.85% vs. -18.96%), peak isometric force (+7.21% vs. -4.73%), and bench press (+3.85% vs. +1.85%) as compared to the control across testing times. The control group experienced superior increases in jump height (+7.29% vs. -0.04%) and peak power (+4.43% vs. +4.17%) as compared to the VBT group.

The hypothesis that the VBT group would show significantly higher improvements in jump height, mean rate of force development (MRFD), peak power, peak force during an isometric quarter-squat, and bench press estimated one-repetition maximum (1RM) was not supported by the current data. No significant interaction between the groups was found for any of the dependent variables. The sole significant main effect observed was increased peak power over time across both groups.

Figures 1-5 display the interactions between the groups for each dependent variable over time.

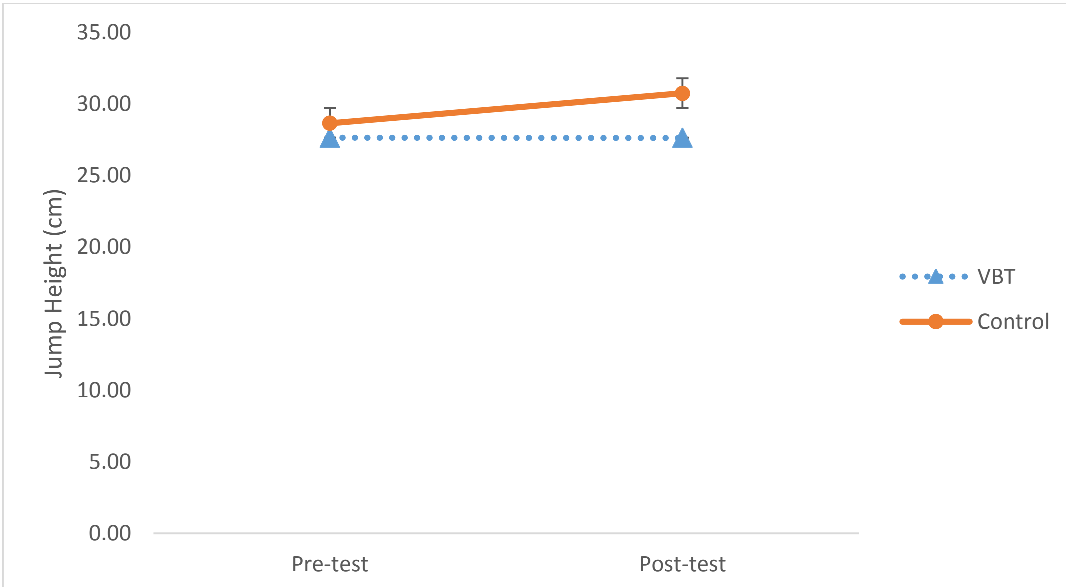


Figure 1. Effects of time and group on countermovement vertical jump height.

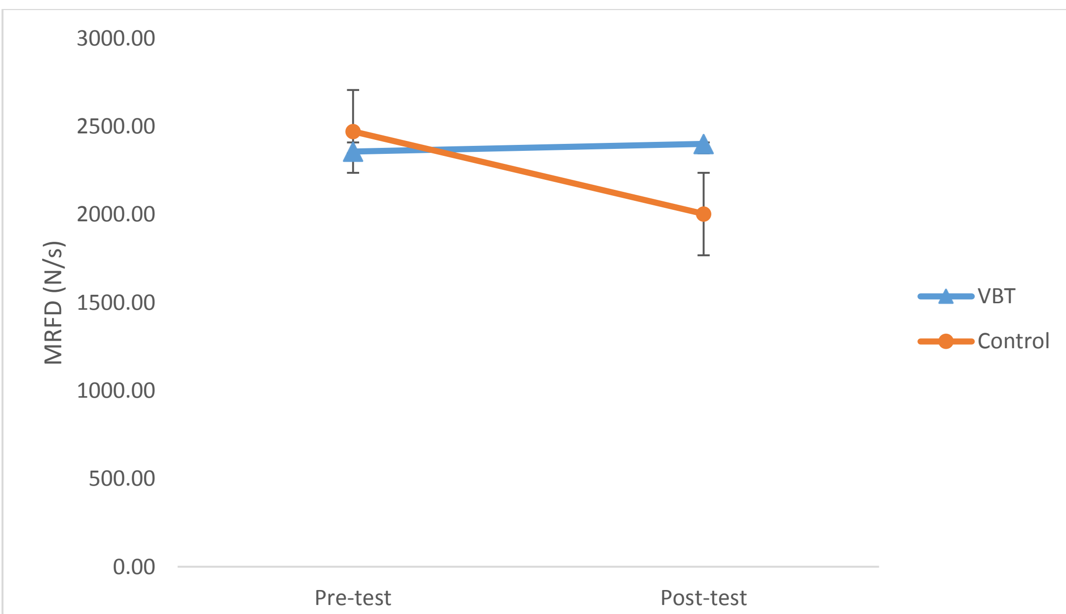


Figure 2. Effects of time and group on mean rate of force development in a countermovement vertical jump.


Figure 3: Effect of time and group on peak power in a countermovement vertical jump.

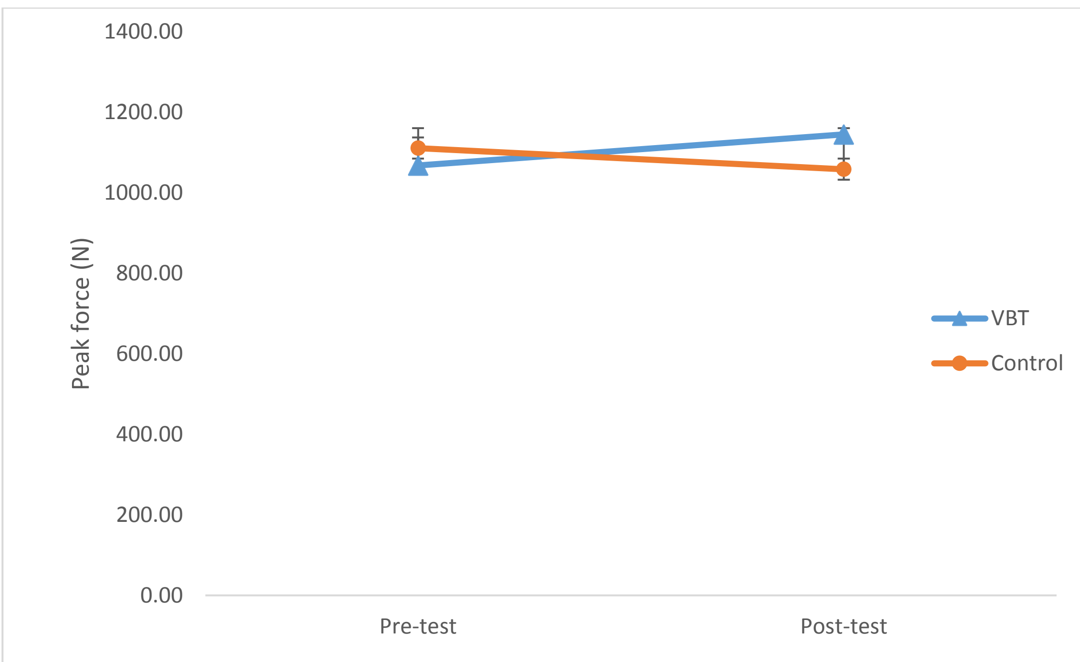


Figure 4: Effect of time and group on peak force in an isometric partial squat.

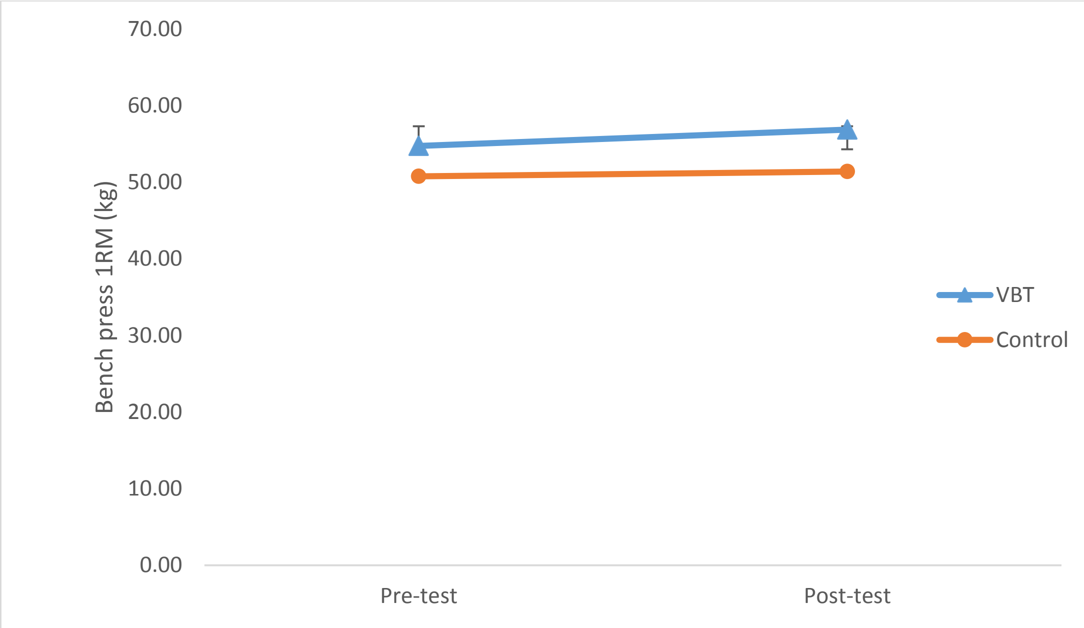


Figure 5: Effect of time and group on bench press one-repetition maximum.

The average total number of repetitions and average total volume lifted for both bench press and back squat differed between the groups, as shown in Table 3.

**Table 3: Volume, Repetitions, and Load/Repetition over Six-Week Training Period**

| | **Mean ± SD** | |
|---|---|---|
| **Bench Press** | **Control** | **VBT** |
| **Total Volume Lifted (kg)** | 2462.66 ± 610 | 2893.75 ± 874 |
| **Total Repetitions** | 66.14 ± 6 | 73.5 ± 17.7 |
| **Average Load/Repetition (kg/rep)** | 36.95 ± 7.3 | 38.75 ± 5.2 |
| | | |
| **Back Squat** | **Control** | **VBT** |
| **Total Volume Lifted (kg)** | 4011.36 ± 1205 | 5297.16 ± 1264 |
| **Total Repetitions** | 59.25 ± 15.9 | 77.63 ± 10.8 |
| **Average Load/Repetition (kg/rep)** | 63.95 ± 7.5 | 68.2 ± 12.8 |

Statistical analysis via a paired T-Test found no significance for bench volume ($p$ = .546), bench press repetitions ($p$ = .601), bench press load/repetition ($p$ = 649), back squat volume ($p$ = .120), back squat repetitions ($p$ = 0.057), or back squat load/repetition (p = .389).

**Discussion**

The purpose of this study was to determine the effects of Velocity-Based Training with the bench press and back squat exercises on vertical jump height, MRFD, peak power, peak force during an isometric squat, and bench press 1RM. Subjects were paired according to strength in the bench press and back squat relative to bodyweight, and randomly assigned to either the VBT group or the control group for a six week training period that took place during the pre-season phase of the season. The dependent variables were tested before and after the training period.

No significance was found between the groups or for the interaction of time and group for any dependent variable, and no significant main effect of time occurred for any variable except peak power ($p$ = .045, +4.45% control, +4.17% VBT). Vertical jump height increased +7.29% in the control group, but decreased by -0.04% in the VBT group. MRFD (+1.85%) and peak isometric force (+7.21%) increased in the VBT group, while decreasing -18.96% and 4.73%, respectively, in the control group. Bench press 1RM increased in both groups (+3.85% VBT, +1.85% control). Standard deviations were high for nearly all variables, making it difficult to make conclusions about the differences in percentage changes between groups. However, effect sizes for the interaction of time and group for vertical jump height ($\eta^2$ = .222), peak force during an isometric quarter-squat ($\eta^2$ = .152) and bench press ($\eta^2$ = .151), and main effect of time for vertical jump height ($\eta^2$ = .218) and peak power ($\eta^2$ = .273), were large enough to take note.

Prior studies regarding VBT use have primarily addressed potential uses and effects of it (Jidovtseff, et al., 2011; Jovanovic & Flanagan, 2014; Mann, Ivey, & Sayers 2015). No long term training studies using VBT were found. However, previous research that has found other forms of auto-regulation in training equal or superior to conventional training (Kraemer & Fleck, 2007; Mann, et al., 2010).

Table 3 displays that the differences between the group's total volumes appear to be determined by the difference in average repetitions performed, as the average load per repetition values were similar between groups for both the bench press and squat. Differences between the groups were not significant, but back squat repetitions was very close ($p$ = .057). The effect of the number of sets on strength has been examined by a number of studies, though there is no research consensus. Carpinelli and Otto (1998) stated in their review of multi- versus single-set training studies that single set training was as effective if not superior to multiple set training. However, this is disputed by many other studies (Berger, 1962; Kramer, et al., 1997; Kraemer, et al., 1995; Ostrowski, et al., 1997; Kraemer, 1997). The studies that are the most relevant to this study are Kramer et al. (1997) and Schlumberger, Stec, and Schmidtbleicher (2001). Kramer et al. observed that multiple sets not to failure were significantly more effective at increasing parallel squat one-repetition maximum than a single set to failure. Schlumberger et al. found that women with basic strength training experience saw significantly superior increases in strength after completing a three-set protocol twice a week over six-weeks as compared to a single-set protocol twice a week over the same time period. While not exact replications of the present study's protocol, these studies may suggest that increased volume through an increased number of sets may lead to superior increases in strength during multi-joint exercises. Based on the findings of these previous studies, increases in the dependent variables for both groups in the present study may have been limited by the phase of the year that the subjects were in for their sport season. The training program reflected the pre-season phase of the year with an emphasis on increasing power output rather than absolute strength, and as a result consisted of lower training volumes than in earlier phases. As previous studies show that an increased number of sets may lead to increased strength gains, it is possible that statistically significant differences would have been found if the subjects in the present study were in a time of the year that allowed for volume to be increased further.

The average bench press and back squat prior to the study was 54.78 kg bench press and 96.5 kg back squat for the VBT group, and 50.79 kg bench press and 86.93 kg back squat for the control group. While no studies including bench press values for collegiate or elite softball players were found, two studies were discovered that included back squat data. The average back squat seen by Parker et al. (2011) in their study involving NCAA Division III softball players was $83 \pm 17.92$ kg, and Nimphius (2010) observed the average back squat in 18 year old elite softball players to be $82.5 \pm 7.7$ kg. While these studies do not use samples identical to the present study, the samples are similar enough that it may be said that the subjects in this present study do not greatly differ in back squat strength levels from other collegiate or elite softball players.

This study had several limitations regarding the testing and training sessions that may have influenced the results. As subjects were collegiate athletes, they all had class and practice commitments that required first priority when it came to scheduling. As a result, testing and training times differed between subjects according to their availability. All subjects participated in one team session per week, but all other sessions were individually scheduled and ranged from 7:00 am to 6:00 pm. Training time often varied not only between subjects, but also for individual subjects week-week. Brown, Neft, and La Jambe (2008) examined the effect of training time on performance in collegiate rowers. They found that rowers who were of the morning-preferring chronotype had significantly faster rowing times in morning training sessions than those who were not morning-preferring. It is possible that individual results in this study would have differed if testing and training times were consistent for all subjects.

The PUSH armbands that were used for velocity measurements were at times inconsistent, especially for bench press. Over the course of the six-week training period, 17 total errors occurred resulting in no velocity measurement. Of the 17, 15 of these errors were during bench press. As an average of nearly three errors occurred per week, it is possible that this affected the study results. If an error occurred that resulted in no velocity recording, the subject was instructed to complete another set. It is possible that if all sets were recorded that some subjects would have seen a 10% velocity drop off during one of these sets and terminated the training sooner, resulting in fewer sets performed, resulting a lower total training volume over the course of the study. As previous studies have found that an increased number of sets may be correlated with increased strength gains, it is possible that if no errors had occurred that resulted in the sets being terminated early that the VBT group would have seen decreased results for bench press 1RM.

# Chapter V

## Summary, Conclusion, and Recommendations

### Summary

Very limited research exists regarding the use of Velocity-Based Training (VBT). The research or information that does exist focuses on the acute effects and measures of VBT rather than the chronic effects of using VBT to regulate volume or other variables (Jidovtseff, et al., 2011; Jovanovic & Flanagan, 2014; Mann, Ivey, & Sayers 2015). While there is a dearth of research relating to the use of VBT for training regulation, other auto-regulatory methods are effective (Kraemer & Fleck, 2007; Mann, et al., 2010). VBT, however, allows for more time efficient measurements and instant feedback, which may be more beneficial in a collegiate setting in which time is limited. This study shows that using VBT as an auto-regulatory method is a viable method of exercise programming, and is at least as effective as traditional fixed volume programming at improving force and power metrics.

Subjects in this study consisted of 17 NCAA Division II female softball players. The subjects were familiar with all exercises included in the training program, but not with the PUSH armband used for VBT, or the force platform used for testing. The fact the training period took place during the pre-season period of the subjects season could be in part the reason for no significant increases in any of the dependent variables for either group except for peak power. The primary goal during this training period was to increase power output, as increased power output may relate more to sports performance than absolute strength (Young, 2006). Ideally, sport performance metrics would have been compared between the VBT groups to determine if the number of sets performed on a given day or in a given week was correlated with sports performance. However, this is not possible to be accurately evaluated due to the multitude of factors other than physical status that affect sports performance.

The present study indicates that VBT as a form of auto-regulation is equally as effective as conventional programming in regards to its effects on force and power metrics. No significant differences were observed between the groups for any of the dependent variables, and no significant increases were seen over time for any dependent variable except peak power.

## Conclusion

The results of this study indicate that there are no significant differences between VBT regulated variable volume training and conventional fixed-volume training. Therefore, while not an improvement over conventional methods, VBT was a viable method of determining training volumes.

## Recommendations

### Future Research

Much more research is needed regarding the application of VBT for the purpose of regulating training volume. The 10% drop off used to determine the point of training termination in the study was not supported by previous research, so it is possible that different percentage drop off limits may be more effective than the 10% change used in the study. Also, as only NCAA Division II softball players were used in this study, it is unknown if a different population would demonstrate the same results. Research indicates that other advanced training methods such as Post-Activation Potentiation (PAP) may have a greater effect in stronger athletes, potentially due to the higher proportion of Type II fibers that have been observed in high responders to PAP (Hodgson, Docherty, & Robbins, 2005; Hamada, et al., 2000). It is possible that stronger subjects or those with a higher training status may have experienced superior results during VBT training as well. VBT use during a different phase of the training year may lead to different results as changes in training emphasis affect the ability increase or decrease training volumes. More research is needed to determine if VBT would have a greater effect in another phase of training or with a different population.

**Practical Applications**

The ability to regulate volume using an easily and efficiently conducted measurement can be vital for strength and conditioning coaches. According to the results of this study, VBT can provide the ability to make these easy adjustments to daily volume without negatively affecting the training effects on force and power output. During the course of the study, most subjects had at least one session in which the performed the minimum number of sets, and at least one session in which they performed the maximum number of sets. This suggests that VBT may allow coaches to accurately adjust daily volumes to match an athlete's readiness for the day, while knowing that the variations in daily volume will not negatively affect performance.

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# Appendix A

## Informed Consent

**Consent to Take Part in a Research Study**

You are invited to participate in a research study conducted by Damien Fisher, from the Department of Physical Education, Health, and Recreation at Western Washington University. This study involves research on the effects of Velocity-Based Training (VBT) over a six-week period. VBT is a form of auto-regulatory training, which utilizes variations of daily readiness tests to tailor training to each individual's physical ability on the given day. An auto-regulatory method such as VBT should may result in increased training benefits, as the training volume is optimized for the given session. The purpose of this research is to compare the effects of two different methods of periodization models, traditional fixed-volume and VBT regulated flexible volume, on maximal strength, peak power, and mean rate of force development in NCAA Division II collegiate athletes.

If you decide to participate, you understand that the following things will be done to you. You will be asked to fill out a brief form to provide basic information such as age, height and weight. You will be assigned to either an experimental or a control group, and will meet for two testing sessions as well as a familiarization session in addition to your regular training schedules.

The familiarization session will take place with both groups before initiation of the six-week training period. It will consist of instruction in back squat and bench press in addition to other exercises and means that will be used during the training program. The experimental group will undergo additional familiarization with the PUSH armband that will be used for velocity measurements during the training sessions.

The pre- and post-training period testing sessions will consist of countermovement vertical jump testing that will take place on a force platform, prior to maximal strength testing. After a dynamic warmup, two practice jumps will be allowed for familiarization with the test. After this, subjects will complete three trials on the force plate. Subjects will be instructed to complete the jumps with maximal effort, and to attempt to avoid jumping forward off the platform in order to ensure the maximal amount of force would be applied vertically. A Vertec apparatus will be placed adjacent to the force platform to give the athletes a target to jump for. Following the vertical jump trials, peak isometric force output will be determined by performing an isometric quarter-squat into a fixed barbell while standing on a force platform. After completion of the countermovement jump and isometric quarter-squat trials, estimated one repetition maximum (1RM) for the bench press will be determined according to NSCA testing procedures (Baechle & Earle, 2008). A three repetition maximum will be determined, from which the O'Conner formula (1RM = load*(1 + (0.025*number of repetitions)) will be used to estimate the 1RM.

Players from your team that choose to participate will be randomly assigned to either a traditional periodization group or a velocity-based training group. Both groups will undergo six weeks of resistance training.

As with any exercise activity, there are always risks present. These risks include muscle, tendon, and ligament injuries, and fatigue will be present. Discomfort may be present during both the maximal strength testing, and during the training sessions, as you will be encouraged to give maximal effort while completing the exercises. Supervision of training sessions and testing will be done to minimize the risk of injury. You are allowed to withdraw from participation in this study at any time, without penalty.

As a result of your participation in this study, you may experience improvements in strength and power following six weeks of training. In addition, the information gained in this study may help in the understanding of optimal training methods for resistance training in maximizing performance gains.

Any questions you may have regarding this study's procedures will be answered by the primary researchers, Damien Fisher and Dr. Dave Suprak, who can be contacted at Damien.Fisher@wwu.edu or 253-691-3299 and Dave.Suprak@wwu.edu or 360-650-2586, respectively. If you have questions regarding your rights as a research subject, contact Janai Symons, Research Compliance Officer, Western Washington University, Bellingham, WA, 98225, (360) 650-3082 (Janai.symons@wwu.edu). You have been offered a copy of this form to keep.

Any and all data collected will be kept confidential and will be stored on a password protected computer and analyzed by subject number only. Consent forms will be stored separately from the data, in a filing cabinet in a locked laboratory, to ensure anonymity of the subjects. The primary researchers will be the only ones with access to your data.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you are at least 18 years of age, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal rights, claims, or remedies.

Print Name______________________________________________________

Signature______________________________________________________

Date___________________________

# Appendix B

## Human Subjects Activity Review Form

## Human Subjects Activity Review

1. **What is your research question, or the specific hypothesis?**

We hypothesized that the experimental group using Velocity-Based Training (VBT) to regulate training volume will show superior increases in bench press and squat maximal strength, as well as lower body power in the vertical jump as compared to traditional fixed volume based programming.

2. **What are the potential benefits of the proposed research to the field?**

Strength and Conditioning coaches are constantly looking for the most effective and efficient means of programming for the development of athletes. The foundation of successful exercise programming lies in the principle of progressive overload. Consistent overload is necessary to stimulate continued adaptation to training. Over time as the athlete improves their physical qualities, acute variables including, but not limited to, load, volume, time under tension, density of training, contraction regime (i.e. eccentric vs. concentric), range of motion, and/or frequency must be progressively increased to maintain an effective overload. The concept of periodization, or systemic variation in specificity, intensity, and volume, grew out of the need to progressively overload athletes without overtraining (Baechle & Earle, 2008).

While traditional periodization models have been shown to be effective at increasing strength and power in athletes, limitations are present, especially in a collegiate setting when there are many times throughout the year that strength and conditioning coaches are unable to work with the athletes (Kraemer & Fleck, 2007). The primary limitations revolve around the inability of traditional methods to accurately predict the athlete's strength levels and capabilities on a day to day basis. As no attempt is made to determine the athlete's daily readiness levels, the coach has no reliable way of knowing if the prescribed load or training volume is correct for the athlete on the given day (Kraemer & Fleck, 2007; Jovanovic & Flanagan, 2014; Mann, 2013).

Auto-regulation methods are ways to modify acute training variables to match an athlete's readiness level before a given training session (Jovanovic & Flanagan, 2014). Readiness tests are typically conducted prior to or during training, with the session being tailored to an athlete's readiness to train according to a predetermined protocol. If properly implemented, auto-regulation can allow for optimization of training and the avoidance of undertraining and overtraining (Kraemer & Fleck, 2007). Many methods of auto-regulation exist with some of the most common being Flexible Periodization, Auto-regulatory Progressive Resistance Exercise, Rating of Perceived Exertion, Heart Rate Variability, and Velocity-Based Training. While traditional periodization and other auto-regulatory methods rely on percentages based off of a one-repetition maximum (1RM), which can change throughout the training program, VBT adjusts the training session based on the velocity at which the chosen exercise is completed (Jovanovic & Flanagan, 2014). The presence of instantaneous knowledge of performance in the form of velocity readouts allows for immediate adjustment according to the athletes readiness level. VBT can be implemented in a variety of ways, including estimating 1RM, adjusting the number of sets and/or repetitions both inter- and intra-set, and adjusting the load that is performed for a given number of sets and repetitions (Jidovtseff, et al., 2011; Mann, 2013).

While traditional periodization methods have been shown to be effective, they may not be optimal in many situations (Kraemer & Fleck, 2007). Collegiate Strength and Conditioning coaches are often faced with the challenge of developing a large group of athlete's physical qualities over periods of as short as six weeks, often after a season when the athlete may have only training once per week or less. In this situation it may be impossible to determine and individualize the appropriate training volume for each individual athlete. Velocity-based training may allow a coach to safely, effectively, and efficiently adjust training volumes for each athlete even in a large group setting.

Although studies comparing auto-regulatory methods to traditional programming have been conducted, such as with APRE and flexible periodization, there have been no studies comparing the effectiveness of VBT to traditional methods. This study will determine if VBT is a viable auto-regulatory method alternative to traditional programming. The results will be significant as if shown to be more effective that traditional methods, VBT can be a very efficient, timely, and fairly cost effective method of ensuring optimal training sessions for collegiate athletes.

3. **What are the potential benefits, if any, of the proposed research to the subjects?**

If the hypothesis is confirmed, the benefit to the subjects will be increased strength and power, which may translate to improved athletic performance in their sport.

4. **A. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database**.

Subjects will consist of Western Washington University varsity athletes from the women's softball team. All players are required to have been in a periodized collegiate strength and conditioning program for at least one year prior to participation in the study to attempt to ensure that exercise technique would not be a limiting factor in the study. Because of this experience requirement, incoming freshman athletes will be excluded from the study. Coaches of the varsity team were contacted in advance to receive permission to contact the athletes about participating in the study.

**B. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited**.

Seventeen subjects will be recruited from the women's varsity softball team to participate in the study. Inclusion requires that the subjects will be free of any musculoskeletal or neurological impairment or injury. No compensation will be given to athletes who participate in the study.

5. **Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.**

**Instrumentation**: Pre-training and post-training, an AMTI OR6-6 (AMTI, Watertown, MA) force platform will be used for collection of mean RFD and peak power during a countermovement jump. Vertical ground reaction force (GRF) data from countermovement jump trials will be analyzed via custom-written LabVIEW software (National Instruments, Austin, TX) to determine jump height (using the impulse-momentum relationship equation), mean rate of force development (calculated as the slope of the line from maximum unweighting to peak force during the jump), and peak power output (calculated as the highest product of force and velocity during the jump prior to toe-off) from the data gathered during the jumps. Microsoft Excel will be used to find peak force during an isometric quarter-squat. Maximal strength pre-testing for the back squat by way of estimated 1RM will be conducted with a Texas Power bar (Capps Welding, Irving, TX) and in a Hammer Strength HD Elite Half Rack (Life Fitness, Rosemont, IL). Bench press maximal testing will be conducted with the use of a Hammer Strength HD Elite Adjustable Bench (Life Fitness, Rosemont, IL) in addition to the Half Rack and Texas Power bar.

**Measurement techniques and procedures**: Countermovement vertical jump testing will take place on a force platform, prior to maximal strength testing. After a dynamic warmup, two practice jumps will be allowed for familiarization with the test. After this, subjects will complete three trials on the force plate. Subjects will be instructed to complete the jumps with maximal effort, and to attempt to avoid jumping forward off the platform in order to ensure the maximal amount of force would be applied vertically. A Vertec apparatus (Perform Better, West Warwick, RI) will be placed adjacent to the force platform to give the athletes a target to jump for, but will not be used for data collection or analysis. Following the vertical jump trials, peak isometric force output will be determined by performing an isometric quarter-squat into a fixed barbell while standing on a force platform. After completion of the countermovement jump and isometric quarter-squat trials, estimated one repetition maximum (1RM) for the bench press will be determined according to NSCA testing procedures (Baechle & Earle, 2008). A three repetition maximum will be determined, from which the O'Conner formula (1RM = load*(1 + (0.025*number of repetitions)) will be used to estimate the 1RM.

6. **Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.**

No research has specifically investigated the effects of using VBT as a method of regulating volume. However, Mann (2013) has written about forms of this method. All variations of VBT used by Mann are based on the dynamic effort method of lifting. This method is used to increase power output and is executed by lifting a submaximal weight with maximum velocity to encourage the greatest possible recruitment of motor units, despite the submaximal load (Zatsiorsky & Kraemer, 2006). With the ascending/descending method a weight is chosen for the first set that the coach believes will fall within the chosen velocity range for the day. The weight is adjusted for each subsequent set, if necessary, to stay within the chosen velocity range. For example, if the chosen range is 0.8-1.0 m/s and the athlete's three reps are 0.77, 0.8, and 0.75 m/s then the weight would be reduced for the following set in an attempt to stay within the prescribed 0.8-1.0 m/s zone. Another method is to perform a predetermined number of sets at a chosen weight with number of repetitions per set varied, depending on velocity readings. This requires a device that gives immediate feedback during the set, as the athlete would continue each set until the velocity drops below 90% of their best reading. A third method is to have a predetermined weight and repetitions, but continue completing sets until the velocity drops below 90% of the best reading for the day. For example, if the athlete records a repetition at 1.0 m/s during their 3rd set and in the 7th set records a 0.88 m/s repetition, the exercise would be terminated.

The third method provided an inspiration for the structure of this study, as a predetermined load and repetition number will be used, and sets will be completed within a specified volume range until either a 10% drop in velocity occurs or the maximum pre-determined volume for the day is reached. While Mann used a Tendo Dynamometer for his methods, a PUSH armband that uses an inertial sensor to measure velocity will be used in this study due to financial limitations. While no studies have validated the PUSH armband for the bench press and squat to date, a study was conducted that showed validity for several other exercises, and suggests that the device is valid and reliable (Sato, et al., 2015). The use of a portable force platform for collection of data during countermovement jump testing was chosen due to it having been shown to be reliable and valid for measuring force-time data during jumping tasks (Walsh, et al., 2006)

7. **Describe how your study design is appropriate to examine your question or specific hypothesis. Include a description of controls used, if any.**

In this study, we will analyze the effect of different training methods on strength and power metrics over a six-week training period. VBT as a method of regulating training volume will be compared against a traditional fixed-volume program. Maximal strength in the bench press and squat exercises will be examined, and mean rate of force development and peak power will be determined from a countermovement vertical jump on a force plate.

A two-way mixed analysis of variance (ANOVA) will be used to determine the effect of group (traditional vs. VBT) and time (pre-test vs. post-test) on the dependent variables estimated one-repetition maximum (1RM) for bench press, peak force during an isometric quarter-squat, and mean RFD and peak power output during a countermovement vertical jump. The alpha level to determine significance was set at $p < .05$.

The study will be conducted by matching pairs of Western Washington University varsity softball players according to relative strength on back squat and bench press, and then randomly assigning members of each pair to either a traditional periodization group (control) or an experimental group. This will be done to minimize the effect of ability on the study results. The only difference between the groups will be that the experimental group will use velocity measurements to dictate the number of sets, and therefore training volume, completed in the bench press and squat exercises during each session, while the traditional group will use a fixed volume program in which each session’s volume is predetermined. All other exercises and training means applied to the groups will be identical. This study design is appropriate to answer this question because it is directly comparing the effects of a traditionally accepted method of providing progressive overload in a training program for performance enhancement (i.e., linear periodization) to a method that monitors performance on a more acute, set-by-set level, to regulate progressive overload based on participant readiness and performance.

8. **Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.**

Multiple studies have used similar protocols when conducting training studies that compare methods of periodization (Kraemer & Fleck, 2007; Mann, Thyfault, Ivey, & Sayers, 2010; Morales, et al., 2014). As the comparison of training methods requires the methods to be implemented over a period of time, a training study is necessary.

**9. Describe the potential risks to the human subjects involved.**

As with an exercise activity, there are always risks present. These risks include muscle, tendon, and ligament injuries, and fatigue will be present. Discomfort may be present during both the maximal strength testing, and during the training sessions, as subjects are encouraged to give maximal effort while completing the exercises.

**10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.**

Exercise technique will be explained in detail, and monitored by, a NSCA certified strength and conditioning specialist. Research assistants will also be present during both training sessions and pre/post testing to assist in ensuring correct technique and safety. In addition, all subjects will have participated in a strength and conditioning program for at least one year and will be familiar with all the exercises included during the study duration.

**11. Describe how you will address privacy and/or confidentiality.**

Any and all data collected will be kept confidential and will be stored on a password protected computer and analyzed by subject number only. Consent forms will be stored separately from the data, in a filing cabinet in a locked laboratory, to ensure anonymity of the subjects. The primary researchers will be the only ones with access to the data.

# Appendix C

## Data Collection Sheets

## Subject Info and Collection Sheets

### Subject Info and Baseline Collection Sheet

| | **Check Off List** | | | **Comments** |
|---|---|---|---|---|
| | | | | |
| Date | | | | Common Activities: |
| Time (Begun, Completed) | | | | |
| Subject Number | | | | |
| Height (cm) | | | | |
| Body Weight (kg) | | | | |
| Age (yr) | | | | |
| Gender | Male / Female | | | |
| | | | | Injury History: |
| Consent Form Completed | Yes / No | | | |
| | Yes / No | | | |
| Warm-up Completed | Yes / No | | | |
| | | | | Other: |
| Prep force plate and computer | Yes / No | | | |
| | | | | |
| Vertec height adjusted | Yes / No | | | |
| | | | | Mistakes/errors |
| Practice jumps completed | 1 2 | | | Jumps |
| | | | | Test 1 Test 2 Test 3 |
| Jump trials completed | 1 2 3 | | | |
| | | | | |
| Set quarter squat bar height | Yes / No | | | |
| | | | | Squats |
| Practice squats completed | 1 2 | | | Test 1 Test 2 Test 3 |
| | | | | |
| Isometric squat trials completed | 1 2 3 | | | |
| | | | | |
| | | | | |
| | | | | |
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| | | | | |

# Post-Training Collection Sheet

| | Check Off List | | | Comments |
|---|---|---|---|---|
| | | | | |
| Date | | | | |
| Time (Begun, Completed) | | | | |
| Subject Number | | | | |
| | | | | |
| | | | | |
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| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Warm-up Completed | Yes / No | | | |
| | | | | Other: |
| Prep force plate and computer | Yes / No | | | |
| | | | | |
| Vertec height adjusted | Yes / No | | | |
| | | | | Mistakes/errors |
| Practice jumps completed | 1 2 | | | Jumps |
| | | | | Test 1 Test 2 Test 3 |
| Jump trials completed | 1 2 3 | | | |
| | | | | |
| Set quarter squat bar height | Yes / No | | | |
| | | | | Squats |
| Practice squats completed | 1 2 | | | Test 1 Test 2 Test 3 |
| | | | | |
| Isometric squat trials completed | 1 2 3 | | | |
| | | | | |
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Bench Press Pre- and Post-Training Collection Sheet

| | **Check Off List** | | | **Comments** |
|---|---|---|---|---|
| | | | | |
| Date | | | | |
| Time (Begun, Completed) | | | | Other: |
| Subject Number | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Rack height set | Yes / No | | | |
| | | | | |
| Bench position set | Yes / No | | | |
| | | | | |
| Warm-up sets completed | 1 2 3 | | | |
| | | | | Mistakes/errors |
| Trials completed until 3RM found | Yes / No | | | |
| | | | | |
| Bench Press 3RM value: | | | | |
| | | | | |
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# Appendix D

## Training Program Example

# Example Two-Week Block

## Physical Preparation Program
## Western Washington University Softball

### Example Program

**Day 1**

| Dynamic Warmup | Week 1 | Week 2 |
|---|---|---|
| Run in Place x30sec | | |
| Jumping Jacks x30ec | | |
| Split Jacks x30sec | | |
| Standing Twists x20 | Foam roll IT band | 10- |
| Cat-Cow x20 | Foam roll adducters | 10-15 |
| **Movement Prep** | Foam roll glutes | 10- |
| See right | Foam roll upper back | 10- |
| | Foam roll lats | 10- |
| | Bent-knee flops | 6ea |
| **Injury Prevention** | T-Spine Rotations | 6ea side |
| Squat Pattern Primer | Mountain climbers + twist | 6ea |
| Scapular Control Exercise | Groiner + hamstring stretch | 10, |
| Hamstring/Posterior Chain Activation Exercise | Cossack squats | 6ea |
| Rotator Cuff | Rocking hip flexor stretch | 6ea side |
| | Standing T's | 10 reps |
| **Reactive Effort** | | |
| MB Throw variation | | |
| SA MB Throw Variation | | |
| Rotational MB Throw Variation | | |

| Max | Exercise | % | Reps | Load | % | Reps | Load |
|---|---|---|---|---|---|---|---|
| T1 | **Back Squat** | | 5 | bar | | 5 | bar |
| SE | | 55% | 5 | | 55% | 5 | |
| | | 70% | 5 | | 65% | 5 | |
| | | 70% | 5 | | 75% | 4 | |
| | | 70% | (5) | | 75% | 4 | |
| | **Record highest velocity below** | 70% | (5) | | 75% | (4) | |
| | **1: 2: 3:** | 70% | (5) | | 75% | (4) | |
| | **4: 5: 6:** | 70% | (5) | | 75% | (4) | |
| | | | | | 75% | (4) | |
| T2 | **Bench Press** | | 5 | bar | | 5 | bar |
| SE | | 55% | 5 | | 55% | 5 | |
| | | 70% | 5 | | 65% | 5 | |
| | **Record highest velocity below** | 70% | 5 | | 75% | 4 | |
| | **1: 2: 3:** | 70% | (5) | | 75% | 4 | |
| | **4: 5: 6:** | 70% | (5) | | 75% | (4) | |
| | | 70% | (5) | | 75% | (4) | |
| | | 70% | (5) | | 75% | (4) | |
| | **Superset w/ T3** | | | | 75% | (4) | |
| T3 | **Plate Lateral Lunge** | | 6ea | | | 5ea | |
| SE | | | 6ea | | | 5ea | |
| | | | 6ea | | | 5ea | |
| | **Superset w/ T2** | | | | | | |
| T4 | **DB Incline/DB Floor Press (Pitchers)** | | 10 | | | 10 | |
| RE | | | 10 | | | 10 | |
| | | | 10 | | | 10 | |
| | **Superset w/ T5** | | | | | | |
| T5 | **Lying Pallof Press** | | 10ea | | | 10ea | |
| RE | | | 10ea | | | 10ea | |
| | **Superset w/ T4** | | | | | | |
| PW | **Foam Roll/Band Stretches** | | | | | | |
| PW | Perfect Pushup<br>Partner/Coach gives up-down commands | | 1x10 | | | 1x10 | |
| PW | 3-5 Minutes Diaphramic Breathing | | | | | | |

**Day 2**

| Dynamic Warmup | Week 1 | Week 2 |
|---|---|---|
| Run in Place x30sec | | |
| Jumping Jacks x30ec | | |
| Split Jacks x30sec | | |
| Standing Twists x20 | Foam roll IT band | 10-15 |
| Cat-Cow x20 | Foam roll adducters | 10-15 passes |
| **Movement Prep** | Foam roll glutes | 10-15 passes |
| See right | Foam roll upper back | 10-15 |
| | Foam roll lats | 10-15 |
| | Bent-knee flops | 6ea side |
| **Injury Prevention** | T-Spine Rotations | 6ea side |
| Hinge Pattern Primer | Mountain climbers + twist | 6ea side |
| Scapular Control Exercise | Groiner + hamstring stretch | 10, 3sec |
| Hamstring/Posterior Chain Activation Exercise | Cossack squats | 6ea side |
| Rotator Cuff | Rocking hip flexor stretch | 6ea side, 3sec hold |
| | Standing T's | 10 reps |
| **Reactive Effort** | | |
| Jump Variation | | |
| SL Jump Variation 2-3x3-5ea | | |

| Max | Exercise | % | Reps | Load | % | Reps | Load |
|---|---|---|---|---|---|---|---|
| T1 | **Hang Clean** | | 5 | bar | | 5 | bar |
| DE | | | 3 | | | 3 | |
| | | | 3 | | | 2 | |
| | | | 2 | | | 2 | |
| | | | 2 | | | 2 | |
| | | | 2 | | | 1 | |
| T2 | **Deadlift** | 55% | 5 | | 55% | 5 | |
| SE | | 70% | 3 | | 75% | 3 | |
| | | 70% | 3 | | 75% | 3 | |
| | | 70% | 3 | | 75% | 3 | |
| | | 70% | 3 | | 75% | 3 | |
| | **Superset w/ T3** | | | | | | |
| T3 | **Eccentric SA Cable Row (5sec)** | | 8ea | | | 8ea | |
| SE | Half-Kneeling | | 8ea | | | 8ea | |
| | | | 8ea | | | 8ea | |
| | | | 8ea | | | 8ea | |
| | **Superset w/ T2** | | | | | | |
| T4 | **BB Glute Bridge/ SL Glute Bridge (pitchers)** | | 6/6e | | | 6/6e | |
| RE | | | 6/6e | | | 6/6e | |
| | | | 6/6e | | | 6/6e | |
| | **Superset w/ T5** | | | | | | |
| T5 | **X-Band Rows** | | 12 | | | 12 | |
| RE | | | 12 | | | 12 | |
| | **Superset w/ T4** | | | | | | |
| PW | **Foam Roll/Band Stretches** | | | | | | |
| PW | Perfect Pushup<br>Partner/Coach gives up-down commands | | 1x10 | | | 1x10 | |
| PW | 3-5 Minutes Diaphramic Breathing | | | | | | |

# Appendix E

## Randomization of groups

Subject Testing Data

Randomization of Velocity-Based Training (experimental) or conventional (control) group assignment

| **Subject** | **Group** |
|---|---|
| 1 | 2 (experimental) |
| 2 | 2 (experimental) |
| 3 | 2 (experimental) |
| 4 | 2 (experimental) |
| 5 | 1 (control) |
| 6 | 2 (experimental) |
| 7 | 1 (control) |
| 8 | 2 (experimental) |
| 9 | 2 (experimental) |
| 10 | 2 (experimental) |
| 11 | 1 (control) |
| 12 | 1 (control) |
| 13 | 1 (control) |
| 14 | 1 (control) |
| 15 | 1 (control) |
| 16 | 1 (control) |
| 17 | 1 (control) |

# Appendix F

## Raw Data

Subject Characteristics

| Subject | Group | Age (yrs) | Height (cm) | Bodyweight (kg) |
|---|---|---|---|---|
| 1 | 2 | 19 | 64.5 | 75.09 |
| 2 | 2 | 21 | 74 | 146.36 |
| 3 | 2 | 19 | 64.5 | 74.45 |
| 4 | 2 | 20 | 65 | 72.68 |
| 5 | 1 | 19 | 71 | 90.92 |
| 6 | 2 | 21 | 66 | 68.12 |
| 7 | 1 | 21 | 64 | 71.25 |
| 8 | 2 | 20 | 67 | 71.53 |
| 9 | 2 | 19 | 64 | 84.45 |
| 10 | 2 | 21 | 67 | 77.5 |
| 11 | 1 | 20 | 72 | 86.15 |
| 12 | 1 | 21 | 67 | 70.45 |
| 13 | 1 | 22 | 62 | 76.66 |
| 14 | 1 | 21 | 64 | 59.35 |
| 15 | 1 | 21 | 64 | 77.5 |
| 16 | 1 | 21 | 67 | 83.7 |
| 17 | 1 | 20 | 64 | 66.79 |

# Subject Test Data

## Pre-Training Tests

| Group | Subject | Jump Height (cm) | MRFD (N/s) | Peak Power (W) | Peak Force (N) | Bench Press est 1RM (kg) | Back Squat est 1RM (kg) (no post-test) |
|---|---|---|---|---|---|---|---|
| 2 | 1 | 26.62 | 2085.26 | 3484.92 | 1193.87 | 50.83 | 104.45 |
| 2 | 2 | 15.51 | 2530.44 | 4353.61 | 884.74 | 62.39 | 111.26 |
| 2 | 3 | 28.49 | 1793.12 | 3429.57 | 856.23 | 57.40 | 104.45 |
| 2 | 4 | 29.95 | 5555.82 | 3446.11 | 1136.02 | 57.22 | 84.01 |
| 1 | 5 | | | | | 67.38 | |
| 2 | 6 | 38.71 | 2441.90 | 4067.99 | 1031.23 | 60.51 | 84.01 |
| 1 | 7 | 34.76 | 2163.71 | 3810.03 | 1415.99 | 63.33 | 104.45 |
| 2 | 8 | 25.99 | 1496.20 | 3005.83 | 1143.40 | 54.90 | 77.20 |
| 2 | 9 | 29.65 | 2206.93 | 3636.71 | 1178.07 | 57.40 | 127.16 |
| 2 | 10 | 26.26 | 751.99 | 3050.09 | 1119.31 | 37.43 | 79.47 |
| 1 | 11 | 31.35 | 2621.91 | 4289.66 | 1067.70 | | 84.01 |
| 1 | 12 | | | | | 42.43 | |
| 1 | 13 | 22.30 | 2646.21 | 3175.55 | 1074.87 | 48.41 | 88.56 |
| 1 | 14 | 31.95 | 1299.56 | 2847.75 | 833.39 | 41.15 | 79.47 |
| 1 | 15 | 23.41 | 2309.39 | 2774.30 | 1113.79 | | 84.01 |
| 1 | 16 | 28.15 | 4655.33 | 3690.14 | 1026.26 | 43.57 | 84.01 |
| 1 | 17 | 28.73 | 1608.46 | 3179.88 | 1245.30 | 49.26 | 84.01 |

## Post-Training Tests

| Group | Subject | Jump Height (cm) | MRFD (N/s) | Peak Power (W) | Peak Force (N) | Bench Press est 1RM (kg) |
|---|---|---|---|---|---|---|
| 2 | 1 | 26.86 | 2030.84 | 3666.02 | 1419.3 | 50.83 |
| 2 | 2 | 11.22 | 2355.22 | 3829.36 | 1233.36 | 62.39 |
| 2 | 3 | 29.45 | 1996.63 | 3719.97 | 796.99 | 57.40 |
| 2 | 4 | 28.34 | 3900.66 | 3369.08 | 1268.74 | 62.39 |
| 1 | 5 | | | | | 62.39 |
| 2 | 6 | 39.49 | 2576.69 | 4338.07 | 805.29 | 62.39 |
| 1 | 7 | 39.20 | 2402.47 | 4129.82 | 1324.78 | 62.39 |
| 2 | 8 | 27.42 | 1493.74 | 3208.39 | 1138.38 | 54.90 |
| 2 | 9 | 29.98 | 3453.16 | 3849.83 | 1121.67 | 59.89 |
| 2 | 10 | 28.34 | 1402.71 | 3680.76 | 1375.37 | 44.92 |
| 1 | 11 | 34.56 | 2155.46 | 4401.93 | 1031.55 | |
| 1 | 12 | | | | | 44.92 |
| 1 | 13 | 24.32 | 2222.30 | 3238.02 | 1080.73 | 48.41 |
| 1 | 14 | 35.45 | 1275.87 | 3023.58 | 757.07 | 44.92 |
| 1 | 15 | 23.39 | 1697.62 | 2948.32 | 933.88 | |
| 1 | 16 | 26.46 | 2083.64 | 3616.46 | 861.07 | 43.57 |
| 1 | 17 | 31.89 | 2185.79 | 3462.65 | 1420.69 | 53.25 |

Subject Training Data

Volume and Repetitions Performed Over the Six-Week Training Period

| | | Bench Press | | | Back Squat | | |
|---|---|---|---|---|---|---|---|
| Subject | Group | Total Volume Lifted (kg) | Total Repetitions | Average Load/Repetiton (kg/rep) | Total Volume Lifted (kg) | Total Repetitions | Average Load/Repetition (kg/rep) |
| 1 | 2 | 2788 | 74 | 37.68 | 5677 | 78 | 72.78 |
| 2 | 2 | 2357 | 55 | 42.85 | 4353 | 57 | 76.37 |
| 3 | 2 | 3760 | 95 | 39.58 | 5981 | 80 | 74.76 |
| 4 | 2 | 3817 | 93 | 41.04 | 5388 | 90 | 59.87 |
| 5 | 1 | 3249 | 69 | 47.09 | | | |
| 6 | 2 | 3397 | 77 | 44.12 | 5220 | 87 | 60.00 |
| 7 | 1 | 3249 | 69 | 47.09 | 5125 | 67 | 76.49 |
| 8 | 2 | 2386 | 63 | 37.88 | 3760 | 68 | 55.30 |
| 9 | 2 | 3374 | 85 | 39.70 | 7766 | 85 | 91.36 |
| 10 | 2 | 1249 | 46 | 27.15 | 4194 | 76 | 55.18 |
| 11 | 1 | | | | 4019 | 67 | 59.99 |
| 12 | 1 | 1916 | 65 | 29.48 | | | |
| 13 | 1 | 2375 | 69 | 34.42 | 4260 | 67 | 63.58 |
| 14 | 1 | 2191 | 69 | 31.76 | 3776 | 67 | 56.36 |
| 15 | 1 | | | | 4089 | 67 | 61.04 |
| 16 | 1 | 1683 | 53 | 31.75 | 1926 | 31 | 62.11 |
| 17 | 1 | 2559 | 69 | 37.09 | 3122 | 51 | 61.22 |

# Appendix G

# Statistical Data

Statistical Analysis Tables

Two-Way ANOVA

Vertical Jump Height

**Tests of Within-Subjects Contrasts**

| Source | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Time | Linear | 8.065 | 1 | 8.065 | 3.633 | .079 | .218 |
| Time * Group | Linear | 8.221 | 1 | 8.221 | 3.703 | .076 | .222 |
| Error(Time) | Linear | 28.859 | 13 | 2.220 | | | |

**Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Intercept | 24558.952 | 1 | 24558.952 | 311.848 | .000 | .960 |
| Group | 31.873 | 1 | 31.873 | .405 | .536 | .030 |
| Error | 1023.789 | 13 | 78.753 | | | |

Mean Rate of Force Development

**Tests of Within-Subjects Contrasts**

| Source | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Time | Linear | 337603.992 | 1 | 337603.992 | .796 | .389 | .058 |
| Time * Group | Linear | 489857.504 | 1 | 489857.504 | 1.154 | .302 | .082 |
| Error(Time) | Linear | 5515978.487 | 13 | 424306.037 | | | |

**Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Intercept | 159175033.479 | 1 | 159175033.479 | 94.278 | .000 | .879 |
| Group | 150054.850 | 1 | 150054.850 | .089 | .770 | .007 |
| Error | 21948690.485 | 13 | 1688360.807 | | | |

Peak Power

**Tests of Within-Subjects Contrasts**

| Source | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Time | Linear | 166688.769 | 1 | 166688.769 | 4.892 | .045 | .273 |
| Time * Group | Linear | 8.745 | 1 | 8.745 | .000 | .987 | .000 |
| Error(Time) | Linear | 442919.531 | 13 | 34070.733 | | | |

**Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Intercept | 376829207.879 | 1 | 376829207.879 | 890.388 | .000 | .986 |
| Group | 198239.539 | 1 | 198239.539 | .468 | .506 | .035 |
| Error | 5501849.233 | 13 | 423219.172 | | | |

Peak Isometric Force

**Tests of Within-Subjects Contrasts**

| Source | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Time | Linear | 1122.715 | 1 | 1122.715 | .083 | .778 | .006 |
| Time * Group | Linear | 31320.003 | 1 | 31320.003 | 2.310 | .152 | .151 |
| Error(Time) | Linear | 176221.875 | 13 | 13555.529 | | | |

**Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Intercept | 35848950.601 | 1 | 35848950.601 | 529.491 | .000 | .976 |
| Group | 3478.123 | 1 | 3478.123 | .051 | .824 | .004 |
| Error | 880158.523 | 13 | 67704.502 | | | |

Bench Press One-Repetition Maximum

**Tests of Within-Subjects Contrasts**

| Source | Time | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|---|
| Time | Linear | 66.996 | 1 | 66.996 | 3.131 | .100 | .194 |
| Time * Group | Linear | 20.041 | 1 | 20.041 | .937 | .351 | .067 |
| Error(Time) | Linear | 278.141 | 13 | 21.395 | | | |

**Tests of Between-Subjects Effects**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Intercept | 413981.063 | 1 | 413981.063 | 649.430 | .000 | .980 |
| Group | 812.414 | 1 | 812.414 | 1.274 | .279 | .089 |
| Error | 8286.894 | 13 | 637.453 | | | |